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OIL ORGANIC MATTER AND ASPECTS OF PLANT NUTRITION

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ences, USSR

Soil organic matter is of great importance as ource of ash and carbon nutrient for plants. e total contents of such important elements as rogen and phosphorus in the organic part of soil amount to tons per hectare. Thus, the rogen content of the 0-100 cm layer is ap- oximately 6 metric tons/ha in podzolized ls, up to 12 metric tons/ha in forest-steppe dzolized soils, up to 24-35 metric tons/ha in ernozems, up to 10-15 metric tons/ha in estnut soils, and up to 7-10 metric tons/ha in rozems. Soil humus also contains a con- lerable quantity of phosphorous organic com- unds, amounting to 0.5 metric tons/ha in estnut soils and approximately 1.5 metric s/ha in sierozems when calculated as P_2O_5. ese potential riches are converted and made ilable to plants largely by the extensive bio- ical activity of the soil microflora and fauna.

It would, however, be erroneous to restrict role of organic matter in plant nutrition to t of a reserve supply of ash elements. From ecial studies made in the last few decades it clear that some soil organic matter is in- ved in the physiological and biochemical ocesses associated with plant respiration, tabolism and ash element uptake, which af- t the development and yield of the plant. This ensive group of soil organic compounds in- des vitamins, auxins and other biotic sub- nces that enter the soil partly from root retions, from organic remains of animals vegetables, and from manure and composts various types. They are also formed in con- erable quantities by the living population of soil. A number of research workers have nonstrated the existence of a wide range of amins in the soil. The vitamins include se of the aliphatic series (e.g., pantothenic d), the aromatic series (p-aminobenzoic d) and an assortment of soil vitamins of the erocyclic series (nicotinic acid, pyridine ivatives, thiamine, biotins, riboflavin, folic d, etc.). The vitamin content of 1 ha of the wed layer ranges from a few hundred grams several kilograms (11, 8).[1]

The plant can synthesize in its own tissues all the vitamins that it requires; nevertheless, several workers have established that an additional supply of vitamins via the roots or from a non-root fertilization can be beneficial to the plant, especially in the initial stages of growth (8, 13). This is because there is an intensification in the plant's enzymatic oxidizing systems associated with its respiration (18) and by participation in metabolism (13).

Included in the soil's biotic substances are the auxins, which stimulate plant growth, especially the development of the root system. The synthetic product heteroauxin (β-indole-acetic acid) is used in fruit and vegetable farming on root slips and seedlings, and to hasten the ripening of fruits. The activity of many soil microorganisms causes the soil to produce its own products.

In addition to vitamins and auxins, the soil contains organic matter with antibiotic properties (streptomycin, penicillin, terramycin, etc.) produced by microorganisms. This organic matter influences the composition of microbial coenosis and, if incorporated in the plant, preserves its properties for a long period of time. The plant is thereby protected from infection (8). Penicillin, streptomycin and terramycin also affect the movement of the nutrients N, P_2O_5 and K_2O in the plant (28).

It may be that the soil vitamins, auxins and antibiotics play an active role in the vital processes of plants because they enter via the root system. The large size of molecules of these substances (300, 500 and even 800) is no obstacle to their entry into the plant. Krasil'nikov (8) and Scheffer and Klocke (28) have shown that antibiotics enter the plant in unaltered form. Ratner and Dobrokhotova (14) have demonstrated the same thing for vitamins.

Many separate organic compounds - amino-, dicarbon (especially succinic and fumaric) and other acids — act as biological stimulants. This is established in several papers by Blagoveshchenskiy, who notes that the way in which stimulants of this type participate in plant metabolism is still not entirely clear and suggests that they have a deforming effect on the protein molecules of enzymes. This increases the energy of the latter. The experiments of Blagoveshchenskiy

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[1] ere and elsewhere we shall only cite the authors' ew articles in most cases.

Table 1

The effect of soil solutions on young growth of barley and wheat

Treatment Number	Treatment	Weight of air-dry plant tops, g per pot	Weight of plants as a % of the control	Weight of air-dry roots, g per pot	Weight of roots as a % of the control
	Barley				
1	Control (Knopp's mixture)	0,342	100	0,157	100
2	Addition of soil solution containing 0.54 mg of carbon per pot	0,440	128	0,238	151
3	Addition of soil solution oxidized with H_2O_2	0,464	115	0,212	135
4	Control for treatment 3 - decomposed H_2O_2	0,403	100	0,159	100
		mD (experimental error) ± 5%-6% for both the plant tops and roots			
	Wheat				
1	Control (Knopp's mixture)	0,288	100	0,078	100
2	Addition of soil solution containing 0.14 mg of carbon per pot	0,331	114	0,117	150
3	Addition of soil solution oxidized with H_2O_2	0,353	116	0,123	131
4	Control for treatment 3 - decomposed H_2O_2	0,304	100	0,094	100
		mD (experimental error) ± 4% for the plant tops, ± 12% for the roots			

Note: Comma represents decimal point.

and others have established that treating some types of seeds with weak concentrations of succinic and fumaric acid before sowing has a positive effect on the growth rate, the development of roots and tops and on the size and quality of the yield. Catalase activity, water content and the amount of non-saponified chlorophyll are all found to be increased in the experimental plants (4). This group of biotic substances, which includes organic compounds of specific nature, is extensively produced by the activity of many groups of microorganisms and is unquestionably present in the soil and in soil solutions. This is shown by our own experiments.

We tested the effect of a soil solution obtained by centrifuging fresh samples of sod-podzolic soil on the development of young barley and wheat plants. The experiments were conducted in water cultures of Knopp's mixture, in which $Ca(NO_3)_2$ had been replaced by NH_4NO_3 to avoid the precipitation of humic acids. To each of the vessels containing 125 ml of the nutrient medium we added 20 ml of the soil solution (equivalent to the content in 125 g of soil). Treatment 3 (see Table 1) was included in the experiment to separate the effect of the organic and mineral components in the soil solution. In this treatment the organic matter was first oxidized with hydrogen peroxide. Excess of the latter was removed by boiling, and the solutions were neutralized with an 0.01 N NaOH to the pH of the soil solution. Decomposed and neutralized hydrogen peroxide was used with the ignited soil (treatment 4) as a control of treatment 3. The experiment was replicated three times and took 14 days.

Table 1 shows that the addition of small quantities of soil solution has a positive effect on the plants and that in our short experiments root development is more affected than is top development. Comparison of treatments 1, 2, 3 and 4 clearly shows that the increase in the growth rate is due to the organic part of the soil solution.

Particularly interesting are studies in which the workers establish that not only individual organic compounds but also whole groups of humic matter can be incorporated in the plant's vital processes. Without dwelling on studies dating back to the beginning of the century,[2] we wish to point out that the fundamental investigations of the effect of humic matter on plants were started in the 1930's in the USSR by Blagoveshchenskiy and Prozorovskaya (3) and by the Polish scholars Niklewski and Wojciechowski (24). Recent studies by scholars in various countries show how varied is the participation of humic matter in the physiological and biochemical processes of plants and how significant these processes are to plant nutrition [Prat, (25), (26) - Czechoslovakia; Niklewski, (23), (24) and Guminski, (6) - Poland; Khrista, (19) - USSR; Chaminade, (20) - France; aig, (21) - Federal German Republic].

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[2] See the monographs of Tyurin (16), Waksman (5), and Kononova (7) on soil organic matter for summaries of these works.

The main results of these investigations can formulated briefly as follows: It has been tablished that humic matter (both humic and lvic acids) extracted as highly dispersed col- ids and true solutions from peats, fossil als and soils have a profound and diverse ef- ct on a plant when present in small quantities water and sand cultures.

The humic matter activates the process of ot formation, especially in the plant's early ages of development. The effect of humic ids on the physico-chemical state of plant otoplasm is no less important. Blagovesh- ienskiy and Prozorovskaya (3), Chaminade 0) and Khristeva (17) found that the perme- ility of plant membranes was increased when mic matter was present and that this helped increase the plant's uptake of water and trient elements.

A most important aspect of the many-sided fluence on the plant of small concentrations humic acids and solutions is their capacity activate the enzymatic systems. This in- uence is most clearly seen in the enzymatic xidation-reduction system of plant respira- on. Khristeva, Biber and Magaziner (2), and laig (21) have shown in experiments on plant ssues that oxygen is absorbed more intensive- in the presence of humic acids than in the ontrol experiments. This is explained by the resence in humic acids of polyphenol groups hich activate the phenolases in the respiratory nzymes. It was also established that humic cids affect the oxidation-reduction state of the lant's growing medium. Guminski (6) has emonstrated that humates facilitate plant espiration when there is inadequate oxygen in aqueous medium, owing to the presence in eir molecules of hydroxyquinone groups. hese accept the excess hydrogen formed in the lant tissues.

Flaig observed the interesting fact that small mounts of humic acids and of the specific or- anic compounds thymoquinone and thymohydro- uinone (which also contain quinone groups) in- uence plant metabolism. He noted that carbo- ydratic metabolism is affected when these ubstances are present and that reducible sugars e accumulated in the plant. This latter factor creases osmotic pressure and helps the plant withstand wilting when the relative humidity low. These facts, pointing to the many-sided ole of humic matter in the plant's life are ex- ained as being due to their influence on the ant in the external environment and to entry to the plant. This latter point was demon- rated by Prat's studies (26) with C^{14}- belled humic acid. Radioactivity was de- cted in the roots and leaves of corn grown in nopp's nutrient medium to which C^{14}-labelled mic acid had been added. Prat also found that mic acid penetrated slowly into the plant's ots and spread slowly throughout the whole ant; one can conclude that whole molecules or ry large fragments of the humic acid mole- le enter the plant.

Studies by Sladky and Tichy (31) point to the rect action of various groups of humic matter (alcohol extract, humic and fulvic acids) on plant development, respiratory processes, chlorophyll content and metabolic processes. The humic matter was administered via the root system and by sprinkling the plant tops.

The capacity of humic matter to stimulate physiological and biochemical processes in plants may also explain such an important phenomenon as the more complete utilization by the plant of the elements of ash nutrition from the surrounding medium. This was demonstrated by Khristeva (17), Chaminade (20) and others. The results of one of Chaminade's experiments on rye grass in sand flowing-cultures illustrate the point. The plant was supplied with the essential ash elements and microelements; the nitrogen content in the nutrient solutions varied between 17 and 137 mg/l. The only background to one series of experiments was mineral, while small quantities of sodium humate (2.5 mg/l) were added to the second series. Both the crop yield and the plant's nitrogen uptake differed greatly for the two backgrounds. Values for the yield of rye grass from 8 cuttings during the vegetation period are given in Figure 1.

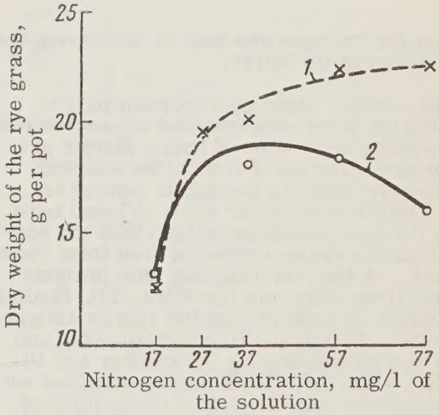

Fig. 1 - The effect of sodium humate on rye grass yield (R. Chaminade, 1958). 1 - with humate; 2 - without humate.

The figures show that the yield is directly dependent on the amount of nitrogen added to the medium only when the quantities of nitrogen are small. Large amounts of nitrogen had an adverse effect on the plant. In the presence of sodium humate, on the other hand, the relationship between yield and the amount of nitrogen in these experiments is preserved. It follows that the presence of small quantities of humate affected the plant's intake and increased the efficacy of mineral nitrogen.

Figure 2 shows the nitrogen uptake. The presence of small amounts of sodium humate assists in the utilization of mineral nitrogen which, in presence of humate, shows injury. Consequently, the presence of small amounts of humus changes the character of requirement by

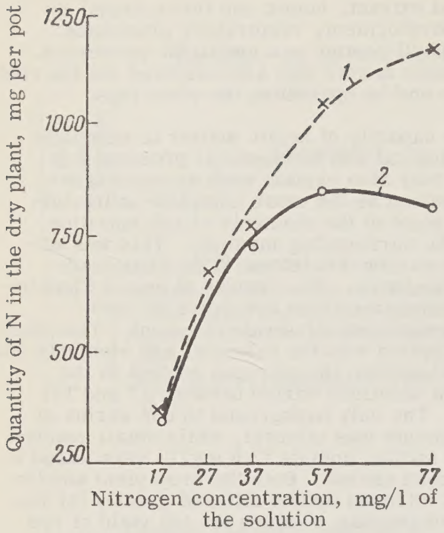

Fig. 2 - Nitrogen uptake by rye grass (R. Chaminade, 1958). 1 - with humate; 2 - without humate.

the plant for nitrogen and aids in increasing the effectiveness of the latter.

Humic matter plays an important part in supplying the plant with iron and microelements. The chelating properties of humic matter prevent the precipitation of iron in the nutrient solution even when the phosphate content is high. The effect of humic acids is found here both in the ionic exchange of iron with the root surface and in the movement of iron from roots to leaves. In the last analysis, this protects the plant from chlorosis (De Kock, 22). Studies by a number of authors [see the review article by Scheffer, Ulrich and Hiestermann (29) and Humus und Humusdüngung by Scheffer and Ulrich (30)] show that plants may be supplied with microelements (Mn, Cu, etc.) in the form of chelates with humic matter or with other organic compounds (lichen and uronic acids, pigments, aminosugars).

These facts are of great importance in solving problems concerning plant nutrition. It is now considered established that the main nutrition of plants is from the consumption of the mineral forms of nitrogen, phosphorus, potassium, sulfur and other elements. At the same time, the participation of many soil organic (and especially humic) substances in the physiological and biochemical processes of the plant shows that plant soil nutrition should not be considered merely as a one-sided and passive consumption of mineral elements. There is constant exchange between the plant and the environment. In this system the plant is the prime source of organic matter, which enters the soil as litter, dead roots and secretions from roots. This organic mass is processed by the living soil population to yield various mineral and organic substances, including some with biotic properties. When biotic substances enter the plant, even in small quantities, they are incorporated in vital processes and affect the nature of the consumption and conversion of the mineral forms of the plant's nutrient elements.

The participation of organic matter in the plant's vital processes is of great practical interest. The materials presented here enhance the significance of such measures as the sowing of annual and perennial grasses and the use of organic fertilizers. The organic matter thus included in the soil not only improves its nutritive status and physical properties but also serves as the prime source of the various biotic substances. This largely explains why mineral fertilizers are most effective in soils enriched with organic matter. The experience of the Central Asian republics, where reliable comparative studies of the efficacy of mineral fertilizers under various soil conditions have recently been made, is extremely convincing. Thus, the authors who have summarized the protracted experiments at the Ak-Kavak Experimental Station of the All-Union Scientific Research Institute for Cotton Growing (1, 9, 15) conclude unanimously that from 1936 to 1954 the increase in the yield of raw cotton per kg of mineral nitrogen in the fertilizer used was 12-14 kg where grasses were not sown and 17-28 kg in the rotation with perennial grasses. In their experiments the authors allowed for the additional uptake of nitrogen from the grasses. The rate of nitrogenous fertilizers was therefore reduced by approximately one third as compared with the treatment without grasses. Mineral fertilizers were found to be highly efficient and their use is correspondingly more "remunerative" on sod-podzolic soils when the latter have been dressed with organic matter (manure) (10, 12).

One way in which the special features of humic matter are employed in agriculture is the use of small amounts of humofos as recommended by Khristeva. Humofos are produced by treating peats and weathered coals with ammonia solution to convert the humic matter to a soluble-active state and to enrich the fertilizer with nitrogen; sufficient superphosphate is then added to the mixture to bring the pH to nearly neutral. The use of 8-10 cntr/ha of humofos in the Southern Ukraine on irrigated chestnut soils and chernozems under various crops, and especially placement application to corn, potatoes, grapes, vegetables and forest plantations, gives a yield that is 20%-30% higher, on average, than that from the control.[3]

Field tests of humofos (prepared by Khristyeva's method) conducted by our laboratory for potatoes on sod-podzolic soil were also positive, but the increase in yield by comparison with the control was somewhat lower than in the Ukraine (12%-22%).

The experimental conditions were as follows: The whole experimental area was given a preliminary dressing of NPK of 45 kg/ha of the primary nutrient. The level of farming was high. Humofos and peat fertilizers were applied when

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[3] See "Humus fertilizers, the theory and practice of their use" (Izd. Khar'kov. un-ta, 1957) by L. A. Khristeva et al.

Table 2

Potato yields in field experiments on sod-podzolic soil

Treatment number	Treatments	1956		1957	
		metric tons/ha	%	metric tons/ha	%
1	Control	38,3	100	34,6	100
2	Humofos	47,0	122	39,0	112
3	Peat + NP + Ca	46,0	120	37,6	109
4	Peat + NP	45,2	118	37,3	107
5	Peat	42,0	109	35,5	102
6	NP	43,6	113	35,9	104
		mD(experimental error) ± 3 — 4%			

Note: Comma represents decimal point.

the potatoes were sown (40 g to each hole, or approximately 1 metric ton/ha of the mixture, which had a moisture level of 200%). Treatments 3, 4 and 6 contained 0.7 g of P_2O_5 and 0.3 g of N in each hole, these quantities being equivalent to the mineral fertilizers added to the peat when preparing humofos (Table 2). The experiments were replicated four times and the replicates were in close agreement.

If we turn to the data for 1956 we see that the humofos gave a yield that was 22% higher than the control, in treatments 3 and 4, on which we had used lowland peat with the addition of NP in quantities equal to the content of these elements in the humofos. Consequently, the use in our experiments of well humified lowland peat made additional treatment to increase the availability of the humic matter unnecessary; all that is necessary with this kind of peat is to supply it with mineral fertilizers — nitrogen and phosphorus. Comparison of treatments 1, 2 and 6 shows that in our experiments the increase in yield from organic matter

Table 3

Weight of dry potato and nutrient uptake by potatoes (1 month after sprouting)

Treatments	Dry weight of tops, g per hill			Nitrogen content as a %		Total nitrogen uptake by plant, g per hill	P_2O_5 content as a %		Total P_2O_5 uptake by the plant, g per hill
	Leaves	Stems	Total weight	Leaves	Stems		Leaves	Stems	
Control	23,5	18,7	42,2	4,86	2,82	1,66	0,40	0,47	0,18
Humofos	28,3	23,7	52,0	4,65	2,43	1,89	0,44	0,44	0,23
Peat + NP + Ca	30,8	23,4	54,2	4,32	2,77	1,98	0,48	0,45	0,25
Peat + NP	28,4	23,6	52,0	4,35	2,76	1,89	0,46	0,45	0,24
Peat	24,4	16,6	41,0	4,88	2,82	1,66	0,40	0,47	0,18
NP	23,0	22,0	45,0	4,38	3,18	1,71	0,48	0,65	0,25

Note: Comma represents decimal point.

Table 4

Weight of dry potato and nutrient uptake by potatoes (at harvest time)

Treatment	Dry weight, g per hill		Nitrogen content as a %			Total nitrogen uptake by plant, g per hill	P_2O_5 content as a %			Total P_2O_5 uptake by the plant, g per hill
	Stems	Tubers	Leaves	Stems	Tubers		Leaves	Stems	Tubers	
Control	657	1880	2,85	0,77	0,84	7,35	0,52	0,25	0,27	1,85
Humofos	810	2300	2,48	0,88	0,80	8,91	0,52	0,23	0,31	2,59
Peat + NP + Ca	820	2260	2,60	0,92	0,85	8,86	0,48	0,28	0,28	2,27
Peat + NP	835	2220	2,53	0,88	0,97	9,40	0,45	0,22	0,31	2,34
Peat	635	2050	2,30	0,80	0,87	7,15	0,41	0,21	0,27	2,21
NP	755	2140	2,55	0,80	0,89	8,66	0,45	0,20	0,27	2,08

Note: Comma represents decimal point.

Table 5

Nitrogen content in barley

Treatments	Uptake of N (mg per pot)		Level of enrichment of the plant mass, % atoms		N^{15} content in the plant mass, % atoms	
	Grain	Straw	Grain	Straw	Grain	Straw
Control	70,5	43,5	8,6	8,6	3,18	3,18
Humofos	86,0	59,0	8,43	8,75	3,12	3,24

Note: Comma represents decimal point.

of the humofos was of the order of 10% for the sod-podzolic soil.

The data in Tables 3 and 4 illustrate the growth of potatoes and their uptake of nutrients (the 1956 experiment).

The markedly positive effect of the application of small amounts of humofos and mixtures of peat and NP was revealed in the earliest stages in the plant's development (Table 3), both in the weight and in the total uptake of nitrogen and phosphorus. The data in Table 3 also show that in the treatments with humus fertilizers there was no observed increase in the percentage content of nitrogen and phosphorus. The total uptake of nutrients was highest in these treatments because of the intensity of the growth processes. The features we indicated concerning the uptake of nutrients were retained throughout the experiment (Table 4).

We obtained similar data for nitrogen uptake from pot experiments with sod-podzolic soil and barley. In this experiment the nitrogen was in the form $N^{15}H_4NO_3$ calculated for 0.1 g of N per kg of soil (Table 5).[4]

The results show an identical relative N^{15} content in both experimental treatments; the total nitrogen uptake in the humofos treatment is greater, because the plant mass was greater.

It is clearly not a matter of chance that in our experiments on sod-podzolic soil small amounts of humofos were less effective than they were in the Ukraine. Flaig and his colleague Saalbach (27) have data which show that small quantities of humic acids and related substances (e.g., thymohydroquinone) facilitate the accumulation of reducible sugars that increase osmotic pressure; this explains why the plants become more resistant to wilting when atmospheric humidity is relatively low (21, 27). In numerous field tests of humic acids and thymohydroquinone these authors found that the beneficial effect is most marked in dry years. This conclusion is supported by our own studies. Thymohydroquinone, kindly made available to us for experiments by Professor Flaig, was tested on sod-podzolic soil in the Moskovskaya Oblast' (i.e., under conditions of adequate humidity) and under arid conditions on ordinary chernozem in the Dnepropetrovskaya Oblast' in field experiments with potatoes. When the potatoes were planted, 0.1 g of thymohydroquinone was placed in each hill; the primary nutrient background was $N_{45}P_{45}K_{45}$/ha for the sod-podzolic soil and $N_{20}P_{30}K_{20}$ for the chernozem.

The data in Table 6 do not reveal any marked differences in the effect of the thymohydroquinon in the treatment; there was, however, a tendency for the preparation to be beneficial in an unusually dry year in the Dnepropetrovskaya Oblast' and to be ineffective on the sod-podzolic soil, where there had been ample precipitation during the growing season of that year.

We reached more definite conclusions from pot experiments in the controlled climate chambers of the Institute of Plant Physiology of the USSR Academy of Sciences. The experiments were conducted with young barley plants in a sand culture. The moisture of the sand was maintained at 60% of maximum moisture capacity and the temperature of the room at 22°C. The data in Table 7 show that the effect of small amounts of sodium humate was most marked when the relative humidity of the air was lowest.

These materials show that the efficacy of small amounts of humus fertilizers must be tested under different soil and climatic conditions.

Table 6

Potato yields in field experiments with thymohydroquinone

Treatments	Ordinary chernozem, Dnepropetrovsk Oblast'		Sod-podzolic soil, Moskovskaya Oblast'	
	in met. t/ha	as a %	in met. t/ha	as a %
Control	9,5	100	30,6	100
Thymohydroquinone	10,2	108	29,0	95
mD (experimental error) ± 3 — 4%				

Note: Comma represents decimal point.

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[4] The N^{15} content in the plant was determined by Ye. A. Plyshevskaya in the Institute of Biophysics of the USSR Academy of Sciences.

Table 7

Results of an experiment with young barley plants in artificial climate chambers, 1958

Treatments	Relative humidity of the air in the chamber							
	45%				75%			
	Dry weight of plant tops		Weight of air-dry roots		Dry weight of plant tops		Weight of air-dry roots	
	in g per pot	as a %	in g per pot	as a %	in g per pot	as a %	in g per pot	as a %
Control (Knopp's mixture)	1,37	100	0,91	100	1,26	100	1,00	100
Thymohydroquinone, 0.33 mg/pot	1,47	107	1,05	115	1,27	101	1,09	109
Thymohydroquinone, 1.65 g/pot	1,42	104	1,06	116	1,28	101	0,96	96
Sodium humate, 5 mg per pot	1,44	105	1,00	110	1,26	100	1,07	107
	mD (experimental error) ± 2.9% for the plant tops and ± 5.4% for the roots							

Note: Comma represents decimal point.

When considering the possible use of small amounts of humus fertilizers it must be remembered that they do not replace mineral fertilizers and that their main effect is to activate the vital processes of the plant.

Small amounts of humus fertilizers cannot be equated with or substituted for normal amounts of manure, peat and other organic fertilizers, which contain biotic matter and also provide carbon and ash nutrients for the plants.

In this article we have not considered the large and complex question of the possibility of plant nutrition by organic matter (amino acids and compounds containing organic forms of phosphorus and sulfur). We note, however, that recent studies and the classical work of Shulov show that plants can absorb similar types of compound that are widely distributed components of the organic part of the soil.

We conclude that one of the conditions for agricultural progress is the creation of a cultivated, biologically active soil. The systematic enrichment of such soil with organic matter is of multiple significance in that it improves the physical properties of the soil, augments the total contents of nutrients and also activates the vital processes of plants. The plant may thus receive the maximum benefit from soil fertility and from applications of mineral fertilizers.

These factors must be considered in any measures to effect a drastic improvement in our agriculture.

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DISTRIBUTION PATTERNS OF ORGANIC RESIDUES IN THE PROFILE OF CHERNOZEMS IN NORTHERN KAZAKHSTAN

YE. V. KULAKOV, V. R. Vil'yams Soil and Agricultural Museum

Many papers (1, 3, 4, 5, 7, 8) have been devoted to the role of plant roots and tops in the processes of soil formation. Kovda (6) and Bazilevich (2) are among those who have recently considered this problem.

Plant residues in soil are a source of humus formation and of available forms of nitrogen, phosphorus and other plant nutrients. The physical properties of the soil are largely dependent on the presence of plant residues.

A study of the plant residue distribution in the soil has great practical significance in soil management practices to increase the yields of agricultural crops.

This paper is concerned with the content of root and other plant residues in the chernozems of Northern Kazakhstan. The data are based on studies of virgin and old cultivated soils in the Kokchetav region, Kazakh SSR, in 1956-1957.

Soil samples were taken from the 0-10 and 10-20 cm layers separately in six profiles every 10 cm from 0 to 100 cm to determine the total content of organic residues in the plowed layer. The roots were to be washed out from samples taken with a metal cylinder of 500 ml capacity. Three samples were taken at 0-10 and 10-20 cm, two at 20-30 cm and only one at each point between 30 and 100 cm.

A typical plot of the given virgin area was selected to take the samples. The "steppe felt" was first cleared from a 1/4 m² area and the top portion of the steppe vegetation was cut off with shears at ground level and subsequently air-dried in the laboratory, and weighed.

The soil samples were taken after plant tops were removed. Since the surface distribution of the vegetation was uneven, the first samples (from the 0-10 and 10-20 cm layers) were taken where the vegetation was thickest or over a tillering node, the second to the side of a tillering node and the third mid-way between tillering nodes. This was done to arrive at a mean value for the total content of organic residues per hectare. In this way samples were taken between 0 and 20 cm at various districts in the region from 28 plots of virgin soil and 20 plots of cultivated soil. Samples were also taken down to a depth of 100 cm from 6 plots (virgin soil, grassland, continuously cultivated land, etc.).

On the cultivated plots samples were taken from areas not under a crop, to determine the quantity of the residues remaining from the previous year. When it was necessary to determine the plant residues from the previous year in the soil at harvest time, the samples were taken from the rows and between rows of spring wheat. Soil samples for analysis were taken from the same areas from the 0-10 and 10-20 cm layers.

The soil samples for washing plant residues were packeted, reduced to air-dryness and weighed before washing. The washing was effected on aggregation analysis sieves with 2, 0.25 and 0.1 mm openings. To separate the organic residues from the soil as completely as possible, the washing-water recovered after passing through the 0.1 mm sieve was passed through a sieve with an 0.05 mm opening, after flocculating the suspensions with aluminum chloride. This fractional washing gave some idea of the content of various fractions of organic residues: large — on the 2 mm mesh, medium — on the 0.25 mm mesh, small — on the 0.1 mm mesh and ultra-fine (root hairs) on the 0.05 mm mesh. The washed fractions were air-dried and weighed on an analytical balance. The data thus obtained were converted to cntr/ha.[1]

Analysis of the total contents of organic residues per hectare on the virgin land and on the cultivated plots showed that there were considerable variations: The average quantity of organic residues in the 0-20 cm layer was 420 cntr/ha on the virgin land and 104.6 cntr/ha on the old cultivated area. The weight of the steppe felt on the different virgin plots varied, on the average, between 9 and 24 cntr/ha.

Comparing our data with those of other authors we discovered discrepancies: Shalyt (11) indicates that the total root content is 197 cntr/ha in the ordinary chernozems of the Streletskaya steppe and 300 cntr/ha in the

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[1] Ye. Ye. Vlasova, a senior laboratory assistant, helped in the processing of the materials.

Table 1

Ratio of roots to tops in the 0-20 cm layer of virgin soils

Soil	Plant group	Total, cntr/ha		Ratio	Steppe felt	Total Productivity
		Roots	Tops		cntr/ha	
Ordinary chernozem	Sheep's fescue-feather grass	420,0	21,0	20,0	9,0	450,0
Meadow-chernozem	Various grasses	423,0	32,3	13,1	24,0	470,3

Note: Comma represents decimal point.

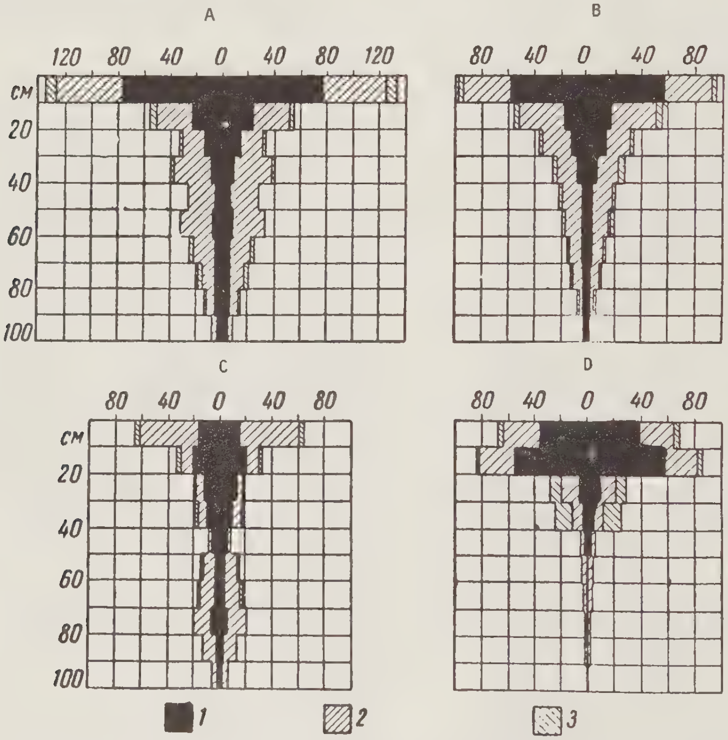

Fig. 1 - Distribution of roots and other plant residues in the profile of southern carbonate chernozems (Prishimskiy sovkhoz, Chistopol'ye district, Kokchetav region)

A - Sheep's fescue-feather grass virgin land; B - non-rooting couch grass, 4th year; C - fallow field before plowing, 5 years after plowing virgin soil; D - old cultivated, spring wheat after fall plowing. Bare ground. 1 = 2 mm; 2 = 0.25 mm; 3 = 0.05 mm.

southern chernozems of the Askaniya Nova. Aydinyan (1) gives 220 cntr/ha for the ordinary chernozems of the Kamennaya steppe. Bazilevich (2) gives 201 cntr/ha for the ordinary chernozems of the Altay subdistrict and Frantsesson (10) gives 249 cntr/ha for ordinary chernozem in the Kustanay region. These discrepancies are due, firstly, to different soil conditions and the different nature of the vegetation and, secondly, to unequal methods for calculating and washing the root system. Unlike the other authors, we did not distinguish between roots proper and other plant residues (underground portions of stems, tillering nodes, stubble residues, etc.). It would therefore be more correct to call our data on root systems in the 0-20 cm layer organic or plant residues. We also used sieves with diameter openings of 0.1 and 0.05 mm when washing the root system. Thus, we avoided the loss of organic residues

Table 2

Average weight of organic residues by fractions, in mm, in the 0-20 cm layer

Land use	Cntr/ha					As percentages			
	Total	>2	>0,25	>0,1	>0,05	>2	>0,25	>0,1	>0,05
Virgin land	423,0	205,0	170,0	40,0	8,0	48,48	40,19	9,45	1,88
Old cultivated land	117,3	32,6	60,2	18,4	6,1	27,78	51,33	15,69	5,2

Note: Comma represents decimal point.

that must occur with the larger mesh sieves (1 and 0.25 mm) used by other investigators.

When using a 1-mm mesh sieve we found (8) that the maximum quantity of organic residues was 290 and the average 250 cntr/ha.

Our studies and those of other authors have established, as can be seen from Table 1, that the ratio of the root to the tops increases with increase in the dryness of the soil, and conversely.

In a normal chernozem under relatively more arid conditions the accumulation of the underground organic material is 20 times greater than the top material; 13 times greater on a meadow-chernozem under more humid conditions. The total productivity of the meadow-chernozem soil is greater than that of the ordinary chernozem.

The distribution of root and other plant residues in the profile of virgin and old cultivated soils can be assessed from the data presented in Figure 1. It can be seen that approximately 35% of the total quantity of root and other plant residues in a meter layer is in the 0-10 cm layer in virgin soils and approximately 50% is in the 0-20 cm plowed layer. The quantity of root residues gradually decreases with depth, but it is still quite significant at a depth of 70-80 cm. The pattern of root distribution beneath sown grasses (couch grass in the fourth year) is similar, although the absolute total amounts are somewhat lower than on virgin lands.

A different pattern can be seen on old cultivated soils. Here the main plant residues lie within the limits of 40 cm from the surface, and the absolute quantities are considerably lower than on virgin soil and under grasses. On a fallow plot five years after the plowing of the virgin land, the organic residues of the virgin steppe vegetation in the upper part of the profile were almost totally decomposed. They were only preserved in the lower part. We conclude that organic residues decompose more rapidly in the upper than in the lower part of the profile.

Comparing the nature of root and other plant residue distribution on virgin and old cultivated land, we see clearly that chernozem was formed beneath perennial steppe vegetation. After the plowing of the virgin lands, soil formation enters a new stage in which it is influenced mainly by annual crops and for which man is largely responsible by his systematic cultivation of the soil, application of fertilizers, etc. If farming methods are incorrect there can be a reduction in soil fertility, but, on the other hand, "the soil constantly improves if it is properly handled" (Karl Marx).

Perennial steppe vegetation develops a deep and greatly branching root system. We have found that a great many sheep's fescue and feather grass roots reach a depth of 1.2-1.3 m. Penetration of the roots to this depth enables the plants to absorb moisture from the lower soil horizons.

Annual crops are less capable of developing a root system. Our data (Figure 1) for spring wheat show that only single (primary) roots reach a depth of 80-90 cm and that the main mass of secondary roots lies within 40 cm of the surface. This root system draws moisture primarily from the upper soil horizons. Therefore the moisture of atmospheric precipitation must be accumulated and retained to ensure high grain yields. It is a feature of the development of grain crops (spring wheat, oats, barley, etc.) that the secondary root system is formed in the tillering period, by which time, under the conditions of Northern Kazakhstan, the upper 8-10 cm of the soil is often so dry that no secondary root system is formed. One must try soil packing the seeds at this period to draw moisture from the underlying layers.

When virgin land is converted to old cultivated land the total content of organic residues is not only reduced, but the ratio of the various size fractions is altered.

Table 2 shows that large fractions with diameters (>2 mm) predominate on virgin land and medium and small fractions on old cultivated land. The difference is due to the biological features of perennial and annual vegetation and to the conditions under which the organic residues are decomposed.

The rate of decomposition of root and other plant residues depends on the nature of the organic matter, the degree of soil moisture and the intensity of microbiological processes. Fresh plant residues of perennial and annual vegetation decompose most rapidly, whereas coarse old roots of virgin land decompose comparatively slowly and may often be found in plowed land 8-10 years after plowing.

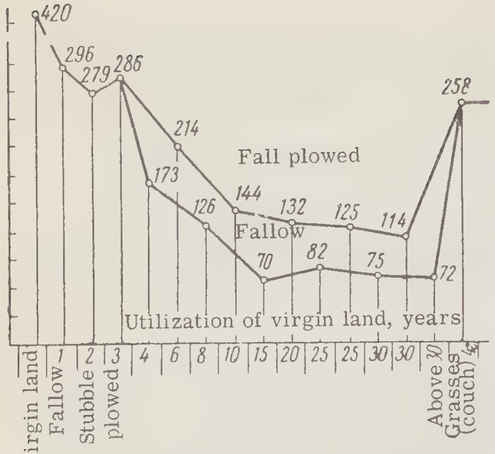

Fig. 2 - Content of organic residues in the 0-20 cm layer, cntr/ha

The role of moisture and microbiological activity is seen by comparing the progress of decomposition on virgin with that of cultivated land (Fig. 2).

Virgin lands are very dry and compacted and microbiological processes are thereby suppressed. The creation in them of conditions that are unfavorable to decomposition is one of the reasons for the accumulation of organic residues. These were shown to average 420 cntr/ha. In the first year after plowing 30%-35% of the initial organic residues is decomposed. This sharp decline occurs because virgin land is usually plowed in late May or early June, when the soil still retains a considerable amount of moisture from the autumn-winter and spring precipitation. If heat and moisture are present during fallow (after plowing of virgin land), microbiological processes develop intensively in the soil. This leads to the rapid decomposition of fresh plant residues. In the second and third years after plowing virgin land, approximately 15%-20% of the remaining plant residues is decomposed, i.e., the process of decomposition is decelerated somewhat. This is partly because only old roots, which are more difficult to decompose, are left in the soil by this time, and partly because the extensive drying out of the soil in the summer by spring wheat suppresses the activity of microorganisms thereby slowing the decomposition of organic residues. The retarded decomposition of roots and other plant residues occurs also because when spring wheat is sown on tilled stubble only the upper layer of the soil is disturbed.

The subsequent course of decomposition depends on whether the spring wheat is sown on fallow or fall plowed land. Figure 2 shows that there are always more organic residues on fall plowed than on fallow land. This indicates that fall plowing creates less favorable conditions for the decomposition of organic residues than does fallow. Fall plowing is, of course, carried out late in the year after the harvest, at a time when microbiological processes are dying down owing to the decrease in air and ground temper ture. Under these conditions the plant residue decompose very slowly and are almost fully retained in the soil until the spring of the followin year. The fact that the soil remains cold in Northern Kazakhstan for a long time in the spring also retards the development of microbiological processes. In summer the limiting factor is the lack of moisture beneath an agricultural crop. As a result, more of the plant residues from the previous year are retained on fall plowed plots than on fallow plots. It is typical that 8-10 years after virgin land is plowed the content of root and other plant residues in the soil becomes more or less stable decomposition of the sod ceases and a balance typical for the given soil group and method of cultivation is developed between the accumulation and decomposition of organic matter. Thi balance can be greatly affected by sowing peren nial grasses, which (as is clear from Figure 2) accumulate far more organic residues than do annual agricultural crops. The accumulation o root and other plant residues increases potenti soil fertility. For this potential fertility to become effective the organic residues must be decomposed (mineralized) and the plant food elements that they contain must be liberated.

It is clear from the facts set out previously that, in Northern Kazakhstan, a considerable quantity of organic residues is accumulated beneath annual crops (up to 14 metric tons/ha in the 0-20 cm layer including stubble residue) as well as on virgin land and beneath perennial grasses. On fallow land organic content is almost halved and averages approximately 7.0 metric tons/ha. Thus, even after fallow, there are still considerable amounts of plant residues in the soil, and this, in our opinion, is a positive factor in increasing soil fertility. The plant residues that are retained improve the physical properties of the soil and serve as a reserve for plant nutrients. Farming techniqu should therefore include measures which both help to accumulate organic residues in the soil and regulate their decomposition.

Total decomposition of all the organic residues is as undesirable as is total retention. A definite minimum amount of organic residues must therefore be retained in the soil to maintain a high level of fertility. Analysis of our data (Fig. 2) shows that this minimum amount for the ordinary chernozems of Northern Kazak stan should be taken to be 6-7 metric tons/ha of organic residues.

It has been shown previously that the main o ganic residues in virgin soils (approximately 35% of the total in the layer one meter thick) is concentrated in the uppermost layer — the sod. Approximately 70% of the total amount of roots is contained in the plowed layer. When the virgin land is plowed, the sod is turned into the bottom of the furrow and a layer containing les root residues (approximately 30%) is brought t the surface. The distribution of plant residues in the plowed layer is therefore irregular, but this irregularity is gradually evened out as the sod decomposes and disappears entirely in fallow on old cultivated land.

The irregularity subsequently reappears wh

Table 3

Distribution of organic residues in the upper layer of virgin and old cultivated soils, percentages

Depth, cm	Virgin soil	Sod	Inverted sod. Sowing on stubble plowing, 1st year	Sowing on stubble plowing, 2nd year	Spring wheat on fall plowed clean ground	Fallow	Spring wheat after harvest
0—10	70,4	28,2	39,3	51,9	41,2	48,7	65,8
10—20	29,6	71,8	60,7	48,1	58,8	51,3	34,2

Note: Comma represents decimal point.

spring wheat is sown on fallow land, but there are less organic residues than there are in the virgin soil.

Thus, irregular distribution of plant residues in the plowed layer is an unavoidable and normal feature. The degree of the irregularity has a fundamental effect on the structure of the plowed layer and on its fertility.

On soils subject to wind erosion the organic residues accumulated by grain crops should be retained in the surface layer, where they act in part as a mulch, in addition to protecting the soil from wind erosion and improving its physical properties. In these districts there is every justification for such farming measures as disking (stubble plowing), stubble plowing without moldboard and the application of organo-mineral mixtures in cultivation before sowing.

The formation and breaking down of the soil structure is closely connected with the accumulation and decomposition of root and other plant residues.

Table 4 shows that virgin lands contain 70%-80% of water-stable aggregates >0.25 mm in diameter. Approximately half of these are >3 mm in diameter. The total content of water-stable aggregates >0.25 mm in diameter decreases to 40%-60% (depending on soil texture) within 6-7 years after plowing virgin land, i. e., by the time the main mass of sod has decomposed. There is a sharp decline in the quantity of large aggregates and an increase in the small aggregates (1-0.25 mm in diameter) and microaggregates between 0.25 and 0.05 mm in diameter,

Table 4

Aggregate and microaggregate analyses of soil in the 0-20 cm layer (according to Astapov)

Location of samples	Land use after plowing	Diameters, mm								Bulk density
		>5	5–3	3 - 1	1—0,25	0,25 – – 0,05	0,05 – – 0,001	>0,25	>0,05	
Aggregates as percentages										
Dzerzhinskiy kolkhoz, Alyk-Balyk district	Virg. land	14,77	13,62	30,25	22,15	15,25	3,67	80,79	96,04	1,01
	6 years	5,62	1,05	13,50	34,32	36,98	8,52	54,49	91,47	0,80
Chekhov sovkhoz, Kzyl-Tu district	V. land	25,35	20,00	3,85	26,72	21,00	3,07	75,92	96,92	1,03
	10 years	2,25	5,82	17,17	29,95	43,63	2,46	55,19	98,82	0,82
Il'ich sovkhoz, Chkalov district	V. land	25.45	12,10	14,70	16,75	25,97	4,59	69,00	94,97	1,31
	25 years	7,27	5,52	8,40	30,25	41,81	6,74	51,44	93,26	0,97
"30 years of Kazakhstan" kolkhoz, Shchuchinsk dist.	V. land	21.95	30,87	12.10	12,45	20,40	2,22	77,37	97,77	1,06
	25 years	1,25	1,25	21,87	32,37	33,20	10,05	57,24	90,44	0,85
Lenin's Path kolkhoz Kellerovka district	V. land	22,55	8,45	27,75	12,87	15,87	2,5	81,62	97,49	—
	20 years	0,0	1,12	10,00	28,62	51,42	8,83	39,74	91,16	--
Bulayevsk district N. Kazakhstan region	V. land	27,35	20,60	9,55	15,87	23,87	2,91	73,37	97,24	1,06
	25 years	0,0	11,10	18,00	32,27	32,55	6,10	61,37	93,92	0,85

Note: Comma represents decimal point.

but only a very slight increase in particle diameters <0.05 mm (down to 0.001 mm in diameter). The total amount of aggregates and microaggregates >0.05 mm in diameter on old cultivated soils therefore remains considerable (90%-95%). Destruction of the large aggregates converts the porous-granular structure of virgin soils to silty powder-like structure. It is a feature of this soil that it is extremely resistant to further destruction, as is shown by data for the aggregation analysis of 20-30-year-old cultivated plots. Aggregates between 0.25 and 0.05 mm in diameter are particularly stable.

The silty powder-like structure of these soils makes them highly permeable to water and gives them a friable consistency. Their bulk density varies in the range 0.8-1.0. These soils do, however, have negative as well as positive features. One negative feature is the ease with which they are eroded by wind.

Observations show that structural virgin soils are not subject to wind erosion for 6-7 years after plowing, owing to the fixation of the small aggregates by small roots of the virgin vegetation. The absence of this linking between the aggregates in old cultivated soils makes them susceptible to shifting by the wind. Silty particles and microaggregates <0.25 mm in diameter are especially susceptible to wind erosion. As a result of wind erosion the soil loses not only clay particles but is also denuded of humus, nitrogen, phosphorus and other plant nutrients to a considerable extent. Soil erosion is one of the principle causes of decline in the soil fertility in Northern Kazakhstan. Serious attention must therefore be paid to measures controlling erosion.

The sowing of perennial grasses is one way of controlling wind erosion. Like virgin vegetation, sown perennial grasses improve soil structure, agglomerate separate small aggregates and microaggregates into larger aggregates and thus increase resistance to wind erosion. The sowing of perennial grasses must therefore here be considered primarily as an erosion control measure and the grasses should be sown on soils that are most dispersed and susceptible to erosion.

In districts where there is little or no erosion, high crop yields can be obtained from old cultivated soil for 25-30 years after the initial plowing of virgin land, if the farming system is correct. Thus, for example, on the Paris Commune kolkhoz in the Aryk-Balyk district, the average yield of spring wheat on 4362 ha of old cultivated soils in 1956 was 19.03 cntr/ha, and in 1958 over the whole area sown on clean fallow it was 15.04 cntr/ha. This and other examples show that, in districts not subject to wind erosion, old cultivated soils retain their fertility for a long time. Further increase in their fertility should be based on improvement of their water regime, the use of fertilizers and basin irrigation and on general agricultural improvement.

Conclusions

1. The virgin ordinary chernozems of Northern Kazakhstan are highly fertile. Our data show that the total humus content in the 0-50 cm layer attains 350 metric tons/ha, the nitrogen 23-25 metric tons/ha, and that the phosphorus and potassium contents of the 0-10 cm layer vary within the ranges 0.15%-0.18% and 1.8%-2.0%, respectively.

2. A high content of root and other plant residues is an important index of the potential fertility of virgin soils. Our data show that the average content in the 0-20 cm layer on virgin land is 420 cntr/ha.

3. Intensive decomposition of organic residues starts after virgin land is plowed and the total content decreases to 50-70 cntr/ha within 8-10 years. There is simultaneous destruction of 0.25 mm diameter water-stable aggregates, the content of which falls from 75%-85% to 50%-55%.

4. Investigation of the distribution patterns of organic residues in the profile of chernozem soils helps explain the genesis of the soils and provides a basis for the development of farming techniques to maintain and improve fertility.

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DYNAMICS OF SOIL ORGANIC MATTER UNDER CONTINUOUS RYE

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A study of continuous crops throws considerable light on such important problems as the supply of nutrients to plants, the resistance of plants to disease and the continuance of soil fertility. An investigation of the dynamics of soil organic matter beneath one crop is of great interest. It is clear that some questions can be solved more easily by experiments with single crops where the complex effect of rotation conditions is excluded.

Some long-standing single crops are listed in Table 1.

A single crop experiment with winter rye, which has been called "perpetual rye" (Ewiger Roggenbau), was established at Halle a. d. Saale in 1878. Many authors have studied this experiment (13, 11, 27, 19, 10, 9, 20, 21, 22, 17, 18).

The "perpetual rye" experiment is now being conducted by Professor Schmalfuss, Director of the Institute of Plant Nutrition and Soil Science at the Halle-Wittenburg University. The author of the present paper studied the soil organic matter under "perpetual rye" at the Institute of Agriculture and Plant Production at this university. The institute is headed by Professor Könnecke.

The originator of the experiment, Professor Kühn (13) of the Halle-Wittenburg University, set out to compare the effect of mineral fertilizers and manure on continuous rye. It was also intended to study the effect of the unbalanced use of nitrogen as a fertilizer on the rye yield and to establish the effect of different fertilizers on the soil.

The continuous rye experiment consists of six plots 11.75 x 85.15 m without replications. The plots are separated by bentonite walls. The following fertilizers have been used on the plots since the beginning of the experiment: the first plot has been given 120 cntr/ha of manure every year; the second — PK — 56 kg of P_2O_5 and 90 kg of K_2O; the third — NPK — 40 kg of N, 56 kg of P_2O_5 and 90 kg of K_2O; the fourth — N — 40 kg of N; the fifth is a control (no fertilizers); the sixth — 80 cntr/ha of manure (started in 1893 with no fertilizer of any sort since 1953).

The texture, as determined by Kühn (13) at the outset of the experiment and by Merker (17) in 1953, is almost unchanged; the soil contains approximately 20% of particles <0.02 mm in diameter. The morphological structure of the profile is as follows: A_1 0-30 cm, humus coarse clay loam[1]; A_2 30-80 cm, humus clay loam, a little lighter in color; C_1 80-100 cm, sandy loam; at 100 cm there is a thin layer of porphyry, quartz and other pebbles, below which there is clay (C_2). There is no evidence of podzolization.

Climatic conditions — mean annual precipitation for 100 years — 501 mm, mean annual temperature 9.2°C. The amount of precipitation is greatest between May and August.

Table 2 gives the average grain yields of "perpetual rye." Yields from all plots have fallen to some extent since the beginning of the experiment, and it is only on the manured plot that it has remained at a level of 25-28 cntr/ha throughout, with the exception of the periods 1909-1918 and 1919-1928. The variations in yield on the various plots have been examined in relation to the fertilizers, the nitrogen balance in soil and plants and climatic conditions. This can be found in papers by Schmalfuss (22) and Könnecke (12). The only important point here is that the varying yields of the plots have undoubtedly affected the amounts of organic matter entering the soil as dead roots and crop residues. Their entry into the soil is one reason for the prolonged fertility of the control plot and the N and PK plots. In relation to the nitrogen supply of the PK and control plots, Schmalfuss (22) came to the conclusion that 20-25 kg/ha of nitrogen, only a small part of which is fixed by nitrogen-fixing bacteria, enters the soil annually with atmospheric precipitation. In Schmalfuss's opinion nitrogen-fixing microorganisms only account for 1.5 kg/ha of nitrogen a year.

Values for pH, hydrolytic acidity and available phosphorus and potassium determined in 1929, 1949 and 1953 by Scheffer (20), Schmalfuss (22) and Merker (17) are given in Table 3. These data show that in a 20-year period (1929-1949) the pH of manured plot 1 and especially of the PK and control plots decreased, while that of the NPK and N plots did not change. It should

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[1] This soil classification is used in Halle.

Table 1

Continuous crops of long standing

Year of first harvest	Crop	Location
1844	Wheat	Rothamsted (England)
1852	Barley	Rothamsted
1877	Wheat and Barley	Woburn (England)
1879	Rye	Halle Saale (East Germany Republic)
1886	Rye	Poltava Agricultural Experiment Station

Table 2

Average yields of the "perpetual rye" plots for the ten-yearly intervals from 1879 to 1948 and for 1949-1954, grain in cntr/ha

Years	Farm manure	PK	NPK	N	Control (without fertz.)
1879—1888	27,61	22,99	30,21	29,26	22,27
1889—1898	25,83	19,08	29,09	26,28	18,68
1899—1908	26,26	16,71	25,87	21,76	15,62
1909—1918	22,84	14,00	21,31	17,44	12,34
1919—1928	22,80	14,45	23,46	16,33	10,69
1929—1938	26,32	16,50	24,36	15,87	12,24
1939—1948	24,51	13,06	20,25	15,62	10,50
1949—1954	28,35	12,58	25,70	20,17	11,45
Average for the 76 years	25,57	16,17	25,03	20,34	14,22

Note: Comma represents decimal point.

be noted that the pH of manured plots in the same period was considerably lower. This is clearly due to an intensification of nitrification and to the related acidifying action on the soil of nitrates. The long-term experiment fails to confirm the widely held view that manuring reduces soil acidity. The pH of all the plots was increased and the hydrolytic acidity lowered by liming (for hydrolytic acidity) in 1949.

The amount of available phosphorus and potassium declined somewhat on all plots between 1929 and 1953, but even on the N and control plots these elements were not exhausted. This is clearly because available phosphorus and potassium were returned to the soil with plant residues.

Total Carbon Content

Variation in carbon content is examined in papers by Scheffer (20), Scheffer and Schachtschabel (21), Schmalfuss (22) and Merker (17). We note here the most important results (Table 4). Carbon content increased considerably between 1878 and 1929 on the plot that received 120 cntr/ha of manure annually (manured plot 1), and the organic content then remained stable until 1954.

On the NPK plot the C content in 1954 was the same as in 1878, but was subject to some variation between 1938 and 1952. The decline was most marked on the control plot. Manured plot 2, which has received 80 cntr/ha of manure annually, was started in 1893. It was not studied before 1951, but from 1951 to 1953 the carbon content increased slightly.

Total Nitrogen Content

Total nitrogen content in this long-term experiment was first determined in 1929 by Scheffer (20) and subsequently by Schmalfuss (22) and Merker (17). The results are given in Table 5. Schmalfuss suggests that the considerable difference in nitrogen content between 1929 and 1949 is due to lack of consistency in taking the soil samples, while Merker explains it as being due to simple determination by the Kjeldahl method, without reduction of nitrates.

On all plots except manured plot 1, the nitrogen content and the C:N ratio were the same in 1949 and 1954. There was a slight change in C:N on the manured plot from 13.3 in 1949 to 12.5 in 1954. On manured plot 2 (80 cntr/ha of dung) the N content increased by 5.5% between 1951 and 1954, owing to an increase in the content of organic matter in the soil.

The author's own experimental results from the Halle-Wittenburg Agricultural Institute were published in German (18). The present paper is a brief summary of that.

The contents of total nitrogen and carbon, carbon of humic and fulvic acids and C and N in the various organic fractions were determined in soil samples from the "perpetual rye" plots taken in the autumn of 1953. The fractions were: 1) The fraction directly soluble in an alkaline medium (solvent 0.5% NaOH); 2) The fraction soluble in an alkaline medium after preliminary removal of fraction I and treatment of the soil with 2% HCl; 3) The remainder of the soil sample after removal of fractions I and II; and 4) The carbon and nitrogen of organic matter that passed into solution when the soil was treated with 2% HCl were determined by subtraction: total C — ($C_I + C_{II} + C_{III}$ from the fractions) and total N — ($N_I + N_{II} + N_{III}$ from the fractions).

The organic matter was separated into fractions at room temperature, so as to affect its natural state as little as possible.

This method for the fractionation of humic matter in a single soil sample is shorter than Tyurin's well-known method and is distinguished by a preliminary extraction of organic matter that is directly soluble in an alkaline solution. Neither the wax-resin fraction nor the fraction of humic matter associated with the stable

Table 3

Variations in pH, hydrolytic acidity and available phosphorus and potassium on the "perpetual rye" plots

Plot	pH		Hydrolytic acidity, meq/100 g of soil	Available phosphorus P_2O_5	Available potassium K_2O
	H_2O	KCl		mg/100 g of soil	
1929					
Manure 1	6,60	6,27	6,1	10,8	37,7
PK	6,83	6,66	4,8	15.2	45,5
NPK	6,14	5,68	7,7	13,8	36,6
N	5,83	5,27	9,1	4,1	8,8
No fertilizers	6,65	6,09	5,4	5,0	14,6
1949 before liming					
Manure 1	5,80	5,90	4,0	6,9	28,6
PK	5,85	6,05	3,3	11,7	36,9
NPK	6,10	5,65	6,7	9,9	25,3
N	5,80	5,23	7,8	6,7	10,8
No fertilizers	5,80	5,65	4,7	5,1	6,3
1953					
Manure 1	6,72	6,44	3,3	7,5	26,5
PK	6,92	6,74	2,2	9,8	27,8
NPK	6,55	6,20	4,4	8,9	22,5
N	6,17	5,53	6,3	4,5	6,7
No fertilizers	6.55	6,10	3,5	4,8	6,8
Manure 2	6,61	6,19	4,1	6,5	15,0

Note: Comma represents decimal point.

hydrates of R_2O_3 are extracted by this method. The carbon of humic and fulvic acids is not determined in the separate fractions but only in a separate sample of the soil after decalcifying.

The Kurmies method (14) was used to determine total carbon. It is based on oxidation of the soil sample with a known amount of 2 N potassium dichromate in the presence of concentrated sulfuric acid. The remaining dichromate is determined with N/5 ferrous sulfate and N/10 potassium permanganate.

Total carbon is determined in the following manner: A 2 g sample of the soil is passed through a 2-mm mesh sieve and ground fine. It is then placed in a 250 ml volumetric flask and 40 ml of concentrated sulfuric acid (sp. gr. 1.84) are added. The mixture is shaken gently until the soil aggregates disperse. The flask is cooled in water and 10-15 minutes later 25 ml of a 2 N solution of potassium dichromate are added. The flask is boiled in a water bath for 3 hours. The reaction mixture is shaken twice an hour. After the flask has cooled it is kept cool in water, distilled water is added up to the 250-ml mark and it is left undisturbed for several hours. If the solution level of the reaction mixture decreases it should be brought back to the mark with distilled water and the mixture in the flask should be well shaken. After 10-12 hours without disturbance the soil in the flask will have settled and the solution will be quite clear. A control sample without soil is prepared simultaneously under the same conditions. For the analyses 10 ml of the reaction mixture solution are pipetted and 100 ml of 5% sulfuric acid and 15 ml of N/5 ferrous sulfate are added. Excess of the latter is titrated with N/10 $KMnO_4$.

The results are calculated from the differences between the amount of the N/10 permanganate solution used in titrating the soil sample and the control. Since 4 atoms of equivalent oxygen (O_2) are needed to oxidize one carbon atom, 1 ml of N/10 dichromate solution corresponding to 1 ml of N/10 potassium permanganate solution is equal to 0.3 mg of carbon.

Nitrogen was determined by the Kjeldahl method as modified by Foerster (25, 28), using salicylic-sulfuric acid and sodium thiosulfate to reduce the nitrates. The ordinary Kjeldahl method only determines the organic and ammonium nitrogen of the soil and not the nitrate nitrogen, since the latter is given off as NO_2 when the soil sample is boiled in sulfuric acid.

Distribution of Soil Organic Matter in the Three Fractions and their Carbon and Nitrogen Content

Extraction of fraction I and carbon and nitrogen determination. A 5-g sample of the soil is

Table 4

Total carbon content in the "perpetual rye" plots

Years Author (method)	1878 J. Kühn	1929 F. Scheffer (element analysis)	1938 Scheffer and Schachtschabel	1949 K. Schmalfuss (Knopp-Springer)	1951 J. Merker (Lichterfelde)	1952 J. Merker (Lichterfelde)	1953 J. Merker (Knopp-Springer)	1954 J. Merker (Lichterfelde)
Plot	C in mg/100 g of absolutely dry soil							
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
Manure 1	1240	1640	1740	1660	1620	1660	1680	1710
PK	1240	1170	1230	1180	1080	1090	1180	1130
NPK	1240	1240	1390	1220	1140	1160	1260	1230
N	1240	1230	1340	1180	1100	1130	1210	1170
No fertilizers	1240	1150	1050	1120	1050	1050	1120	1090
Manure 2	—	—	—	—	1360	1400	1500	1460
	Corresponding variations in carbon content as a %							
	1878—1929 $C_1—C_2$	1929—1938 $C_2—C_3$	1938—1949 $C_3—C_4$	1949—1951 $C_4—C_5$	1951—1952 $C_5—C_6$	1952—1953 $C_6—C_7$	1953—1954 $C_7—C_8$	
	As a percentage							
Manure 1	+32,3	+6,1	—4,6	—2,4	+2,5	<2,0	<2	
PK	—5,6	+5,1	—4,1	—8,5	<1,0	+8,3	—4,2	
NPK	<2	+12,1	—12,2	—6,6	<2,0	+8,6	—2,4	
N	<2	+8,9	—11,9	—6,8	2,7	+7,1	—3,3	
No fertilizers	—7,2	—8,7	+6,7	—6,3	0,0	+6,7	—2,7	
Manure 2	—	—	—	—	+2,9	+7,1	—2,7	

Note: Comma represents decimal point.

Table 5

Total nitrogen content in the "perpetual rye" plots

Years Author	1929 Scheffer	1949 Schmalfuss	1951 Merker	1954 Merker	1929 –	1949 –	1951 –	1954 –
	C in mg/100 g of soil				C:N ratio			
Manure 1	109,0	125	131	137	15,0	13,3	12,4	12,5
PK	76,4	91	87	87	15,3	13,0	12,4	13,0
NPK	80,0	95	93	96	15,5	12,8	12,3	12,8
N	74,4	91	88	93	16,5	13,0	12,5	12,6
Control	71,1	86	82	85	16,2	13,0	12,8	12,8
Manure 2	—	—	110	116	—	—	12,4	12,6

Note: Comma represents decimal point.

placed in a 125 ml Shtomann flask to which 70 ml of 0.5% solution of NaOH are added, and the flask is stoppered and mechanically agitated for 6 hours. The shaking is repeated on the following day, and the mixture is filtered through an N-3 glass Nutsch filter into a test tube until the filtrate becomes clear. Then it is once again filtered into a flask for suction. Filtration lasts for several days. When the whole contents of the Shtomann flask (including the soil) are transferred to the filter they are carefully sucked through. The residue in the flask, and in the test tube, is washed with 0.5% NaOH and passed through the same filter. The filtrate is poured into a 100 ml flask.

Carbon determination. A 10 ml sample of the filtrate for oxidation is transferred to a 100 ml volumetric flask with a pipette. The flask is continually cooled, a few drops of concentrated sulfuric acid (from 25 ml for the oxidation) are added and followed a few minutes later by the whole amount. After cooling is complete 5 ml of $K_2Cr_2O_7$ are added. Under these conditions the concentration of sulfuric acid corresponds to its concentration when determining total carbon. The extract is oxidized for 3 hours in a water bath and distilled water is added after cooling. To determine the carbon, 150 ml of distilled water are added to 50 ml of the extract. The moderate concentration of chromate ions in this solution makes it easily possible to determine a change of color when titrating by the Kurmies method.

Nitrogen determination. A 50 ml sample of the filtrate is placed in a Kjeldahl flask. To this, 1 ml of concentrated sulfuric acid is added and evaporated to 2-3 ml. After cooling, the required reagents are added to determine nitrogen by the Kjeldahl method as modified by Foerster.

Extraction and fraction II and nitrogen and carbon determination. After the removal of fraction I, the residue on the glass filter is treated with 2% HCl by the twice repeated addition of the acid followed by suction filtration. The glass filter is placed in a small dish, covered with 20 ml of 2% HCl and left for 2-3 hours. It is stirred with a glass rod from time to time. The HCl is filtered off and the residue washed in distilled water until Ca and Cl ions are removed. The washed soil residue is transferred with 70 ml of 0.5% NaOH to a Shtomann flask, mechanically agitated for 4 hours, then filtered and washed in 0.5% NaOH solution. The filtrate is poured into a 200-250 ml volumetric flask. The extraction is repeated twice and the filtrates are combined (two extractions were found to be sufficient, since a third gave lightly colored solutions). If the soil sample contains a small amount of organic matter one needs 25 ml of the extract to determine carbon and 100 ml for nitrogen. The samples are evaporated and preliminarily neutralized in the case of nitrogen. Carbon and nitrogen are determined under the same conditions as for fraction I.

Determination of C and N in the soil residue after extracting fractions I and II. The C and N in the residues of the soil samples are determined in the same way as total carbon and nitrogen. The residues are first washed in 1% H_2SO_4, dried at 40°C and crushed.

Separation of Humic and Fulvic Acids in Soil Organic Matter and Determination of Carbon

Between 5 and 10 g of soil are treated at room temperature with 2% HCl, filtered through a glass filter, washed with distilled water, 1% H_2SO_4 and again with water until all the chloride and calcium have been removed. The sample is transferred to a 150-ml Shtomann flask, 100 ml of 0.5% NaOH solution are added and the flask is stoppered and mechanically agitated for 6 hours. The extraction is twice repeated, and the soil residue is washed with 0.5% NaOH solution (double extraction was adequate for soil studies). The filtrates are combined, heated in a water bath and 1 ml of concentrated sulfuric acid and left standing for 12 hours. The cooled humic acids are filtered and washed carefully. The fulvic acids remain in the filtrate. The humic acids dissolve in 0.5% NaOH solution. Carbon is determined under the same conditions as for fraction I. The fulvic acids are neutralized, evaporated and dissolved in 0.5% NaOH.

All three fractions are of importance biochemically and agriculturally. The first fraction consists of various organic compounds — sugars, organic acids and other organic matter easily decomposed by microorganisms — humic acids, fulvic acids and their monovalent salts not connected with the mineral part of the soil. This fraction is mobile, readily soluble or dispersible part of the soil's organic matter. It is known that the presence of free humic and fulvic acids in the soil assist the podzolization process.

Fraction II consists mainly of Ca and Mg humates and organic and mineral complexes (clay-humus complexes) which are formed with Ca, Mg, Fe^{+++}, Al and other soil elements. This fraction affects soil structure. The resistance of humic matter to microorganisms and the water stability of the soil aggregates depends on the stability of the link between the separate components of the organic and mineral complexes.

The humates of calcium and magnesium are important components of the organic and mineral complex of the soil. As long aso as 1826 Sprengel (24) contrasted the "mild humus" (milder Humus) formed under the influence of calcium with "acid humus" (sauer Humus). According to Vil'yams (2), the humates of calcium form "active humus"; they cement the separate soil particles together and help to form the soil structure. Many works, especially those of Barbier (7), Meyer (15, 16), Tyulin (5, 26), Aleksandrova (1) and Beutelspacher (8), are devoted to organic and mineral complexes. It should be mentioned that Gedroyts's theory (3) of the soil's adsorption capacity has been of great assistance in the study of organic and mineral complexes.

Samples of the different soils lost a great deal of their characteristic dark color by the successive extraction of humic matter at room temperature (up to and beyond the point of decalcification). We therefore conclude that, except for the humins, the majority of the humic matter passed over in the filtrates of the first two fractions. Only a small proportion of the humic matter, more intimately bonded with the mineral part of the soil, remained unextracted.

Fraction III contains various unaltered or slightly altered plant and animal residues, the products of organic tissues (proteins, cellulose, lignins, resins, waxes, etc.) and that part of the humic matter that is most intimately bonded with the mineral part of the soil. There is still, therefore, a considerable amount of organic matter in this fraction.

In four soils — humus loess-like clay loam (3.8% organic matter), loess-like clay loam, coarse clay loam and sandy loam — 42% to 27% of total carbon was found after the extraction of the humic matter. The soils were considerably decolorized after treatment. This demonstrates the colorative capacity of humic matter. We can conclude that only slightly affected and partly visible plant residues, organic matter and denatured humic matter (humins) still remained in these soil samples. Consequently, fraction III contains a considerable amount of organic matter that has still not succumbed to biological decomposition.

The method described previously was applied initially on Professor Schmalfuss's suggestion, to investigation of the "perpetual rye" plots and, subsequently, to various soils in crop rotations. Some of the most interesting results are given in the article.

Carbon and Nitrogen Content of Different Organic Matter Fractions of the "Perpetual Rye" Plots

It follows from the data in Table 6 that the content of C and N in fraction I on all the plots (columns 5, 6, 8 and 9) exceeded the content of C and N in fraction II (columns 10, 11, 13 and 14). The high carbon and nitrogen content in the dark-colored fraction I and in fraction II, which is also dark in color, shows that a considerable amount of the humic matter is not fixed in the soil, despite the fact that it was limed in 1949.

Approximately half the total amount of organic matter in each plot was soluble in alkaline solutions (fractions I and II, columns 5 and 10). Only on the non-manured plot was the content slightly less. The amount of insoluble organic matter (fraction III) was 40%, and more, of the total carbon content (column 18) and there was a wide C:N ratio in this fraction (column 17). This is evidently due to the accumulation of substances such as lignin from the prolonged cultivation of rye. Rye contains considerable quantities of lignin, which is known to decompose slowly in the soil.

The data for fraction IV (columns 21-24) show that, dependent on the plot, 5.6%-9.3% of the total amount of carbon went into solution after decalcification and that the C:N ratio of the organic matter was very wide.

In Table 7 the carbon content of fraction II is compared with the total carbon content of the humic acids. A practical method for determining the fixation of humic matter can be based on a comparison of the C in fraction II and in the humic acids, both expressed as a percentage of total carbon. The method may be of interest for liming and for adding clay, sand, etc. to soil.

On all the plots the total carbon content of the humic acids was higher than its content in fraction II associated with the mineral part of the soil. Consequently, a considerable part of the humic acids is not fixed, even on manured plot 1 and the PK plot, the reaction of which was nearly neutral. This is clearly due to the mineralogical composition and texture of the soil (the latter being on the boundary between coarse clay loam and sandy loam).

The relationships between the fixation of humic matter and the soil texture and mineralogical composition and also the soil reaction was confirmed by a study of plots of various soils in different crop rotations. Table 8 shows that, whatever the rotation and the fertilizers applied, the absolute carbon content of the humic acids in every soil studied was either lower than the carbon content of fraction II (Etzdorf

Table 6

Carbon and nitrogen content of organic matter fractions in the "perpetual rye" plots. Autumn 1953

Plot	Total		C : N	Fraction I					Fraction II					Fraction III					Fraction IV				
	C	N		Directly soluble in 0.5% NaOH solution					Soluble in 0.5% NaOH solution after extraction of fraction I and decalcification					Insoluble in 0.5% NaOH solution in the residue after extracting fractions I and II					Passing into solution with decalcification (by differences)				
	in mg/100 g of absolutely dry soil			in mg/100 g of absoltly dry soil			As a % of the total		in mg/100 g of absoltly dry soil			As a % of the total		in mg/100 g of absoltly dry soil			As a % of the total		in mg/100 g of absolutely dry soil			As a % of the total	
				C	N	C : N	C	N	C	N	C : N	C	N	C	N	C : N	C	N	C	N	C : N	C	N
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Manure 1	1684	129,7	13,0	666	61,4	10,8	39,5	47,3	227	22,0	10,3	13,5	17,0	696	45,0	15,5	41,4	34,7	95	1,3	73,1	5,6	1,0
PK	1181	86,6	13,6	408	38,7	10,5	34,5	44,7	187	14,5	12,9	15,8	16,7	503	30,3	16,6	42,6	35,0	84	3,1	27,1	7,1	3,6
NPK	1255	96,2	13,6	446	42,7	10,4	35,5	44,4	193	16,1	12,0	15,4	16,7	507	34,0	14,9	40,3	35,4	110	3,4	32,3	8,8	3,5
N	1250	89,8	13,9	432	43,1	10,0	34,6	48,0	173	14,0	12,4	13,8	15,6	542	30,9	17,5	43,4	34,4	103	1,8	57,2	8,2	2,0
No fertilizers	1155	84,5	13,6	372	36,4	10,2	32,2	43,1	166	12,6	13,2	14,4	14,9	512	30,2	17,0	44,3	35,7	105	5,3	19,2	9,1	6,3
Manure 2	1477	114,5	12,9	553	54,3	10,2	37,4	47,4	188	17,2	10,9	12,7	15,0	599	38,0	15,8	40,6	33,2	137	5,0	27,4	9,3	4,4

Note: Comma represents decimal point.

and Messlitz soils) or higher (Merbitz and Neuch). The Etzdorf and Messlitz soils are clay loam, their reactions are alkaline and the humic acids are fixed. The Merbitz soil is a coarse clay loam, its reaction is slightly acid and part of the humic acids are not fixed. The Neuch soil is sandy loam, its reaction is acid and the greater part of the humic acids are not fixed. Laboratory tests show that liming this soil does very little to increase the carbon content in fraction II, for which more clay is needed. The fixation of humic acids in the soil is therefore dependent on its type, mineralogical composition and reaction.

Qualitative indices of the organic matter in the "perpetual rye" soil are given in Table 9. On manured plot 1 (120 cntr/ha annually) the total carbon and nitrogen content is higher than on the other plots, especially the PK and control plots. The total carbon:total nitrogen ratio is narrower on both the manured plots than on the others.

The absolute carbon content of the humic acids and its amount as a percentage of total carbon and in the humic acids:fulvic acids carbon ratio, is higher for the organic matter on manured plot 1 than on the NPK, PK and N plots, or even on manured plot 2 (80 cntr/ha of manure annually), and is far higher than on the control plot. It should be noted that the higher content of humic acids, expressed as a percentage of total carbon, reflects the large amount of organic matter. Only the PK plot shows some slight deviation that is evidently due to its neutral reaction.

In the soil residues (fraction III) after extraction of humic matter, that is or is not combined with the mineral part of the soil, there remains organic matter that is insoluble in a 0.5% solution of NaOH and is low in nitrogen (the carbon:nitrogen ratio varies from plot to plot between 15 and 17.5). Clearly, substances of the type of lignin, accumulated from the prolonged cultivation of rye, predominate.

It is shown previously that a considerable part of the humic acids on all plots is not fixed in the soil.

Conclusion

1. Total carbon and nitrogen is much higher on the plot that has received 120 cntr/ha of farm manure annually for 75 years than on the NPK, and N plots and especially on the PK and control plots. The carbon content of the manured plot increased by 32% after 1878, but remained stable from 1929 to 1953. The carbon content on the NPK and N plots has not altered since the beginning of the experiment, while on the other plots it has fallen slightly.

The carbon:nitrogen ratio on the manured plot is 13:1; on the other plots it is somewhat wider.

2. The absolute carbon content of the humic acids and its amount as a percentage of total carbon and in the humic acids:fulvic acids carbon ratio, is higher for the organic matter on manured plot 1 than on the NPK, PK and N

Table 7

Comparison of the carbon content of fraction II with the total carbon of the humic acids

Plot	pH		Carbon			Carbon	
	H_2O	KCl	Total	Of fraction II	Of the humic acids	Of fraction II	Of the humic acids
			In mg/100 g of absolutely dry soil			As a % of the total	
Manure 1	6,72	6,44	1684	227	478	13,5	28,4
PK	6,92	6,74	1181	187	290	15,8	24,6
NPK	6,55	6,20	1255	193	298	15,4	23,7
N	6,17	5,53	1250	173	297	13,8	23,8
No fertilizers	6,55	6,10	1155	166	218	14,4	18,9
Manure 2	6,61	6,19	1477	188	374	12,7	25,3

Note: Comma represents decimal point.

Table 8

Study of different soils in crop rotations. Comparison of carbon content of fraction II with total carbon content of humic acids

Soils of experiment stations	Plots of different crop rotations	Electrometric pH		Carbon			C of fraction II as a % of the total C	C of humic acids of the soil as a % of the total C
		Salt	Water	Total	of fraction II	of the humic acids		
				C in mg/100 g of absolutely dry soil				
Etzdorf, humus type loess-like clay loam	41	7,38	7,76	2176	802	678	36,9	31,2
	49	7,40	7,66	2291	798	717	34,9	31,3
	8	7,35	7,53	1963	720	585	36,7	29,8
	64	7,37	7,62	2128	813	657	38,3	30,9
Merbitz, coarse clay loam	1	6,05	6,30	1347	287	355	21,3	26,4
	2	6,15	6,44	1454	294	364	20,2	25,0
Messlitz, loess-like clay loam	16	7,29	7,50	1223	294	228	24,0	18,7
	17	7,20	7,41	1167	300	217	25,7	18,5
	22	6,90	7,14	1215	306	253	25,2	20,8
	23	6,80	7,17	1203	287	231	23,9	19,2
Neuch, sandy loam	1	4,50	4,93	1190	57	171	4,9	14,4
	4	4,63	4,85	1323	52	208	4,0	15,7
	3	4,45	4,67	962	0,0	143	0,0	14,9
	8	5,80	6,15	1265	72	201	5,7	15,9

Note: Comma represents decimal point.

plots, or on manured plot 2 (80 cntr/ha of farm manure annually), and is far higher than on the control plot.

3. The residues of the soil samples after extraction of humic matter, that is or is not combined with the mineral part of the soil, consist of organic matter that is insoluble in a 0.5% solution of NaOH and is low in nitrogen (the C:N ratio varies between 15 and 17.5). It is clear that substances of the lignin type, accumulated from the prolonged cultivation of rye, predominate.

4. A considerable part of the humic acids on all plots is not fixed. Comparison of the soil organic matter of a coarse-textured soil under continuous rye and various soils in different crop rotations shows that the fixation of organic matter in the soil is dependent on texture, mineralogical composition and reaction.

5. There is a direct relationship between a high content of soil organic matter and a high content of humic acids expressed as a percentage of total carbon on the old continuous rye

Table 9

Qualitative indices of "perpetual rye" soil organic matter. Autumn 1953

Plot	C	N	Ratio		C of the humic acids		C of the humic acids / C of the fulvic acids
	Total, mg/100 g of absolutely dry soil		C:N	C:N in fraction III	mg/100 g of soil	As a % of the total	
Manure 1	1684	129,7	13,0	15,5	478	28,4	1,48
PK	1181	86,6	13,6	16,6	290	24,6	1,31
NPK	1255	96,2	13,6	14,9	298	23,7	1,31
N	1250	89,8	13,9	17,5	297	23,8	1,32
No fertilizers	1155	84,5	13,6	17,0	218	18,9	0,95
Manure 2	1477	114,5	12,9	15,8	374	25,3	1,24

Note: Comma represents decimal point.

plots and on the plots of various crop rotations. We assume that accumulation of organic matter in a cultivated soil produces an absolute increase in the humic acids and their relative enrichment of the soil humus, expressed as a percentage of the total carbon content of the soil.

6. The potential fertility of the manured plot is higher than that of the NPK plot; the former contains more organic matter with higher qualitative indices. Clearly this is why, in recent decades, the rye harvest on the manured plot has exceeded that of the NPK plot, whereas in the first decades (1879-1898) the reverse was true. The NPK plot was still the most profitable up to 1954, since the average yield for each of the plots for 76 years was the same (25 cntr/ha), while the cost of the farm manure and its transportation and placement was considerably higher than the corresponding expenditure for mineral fertilizers.

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SOIL-WATER REGIME IN A GRAIN-BEET ROTATION

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Because of the forest-steppe and steppe conditions in the Ukraine, the soil-water regime is one of the main factors to be considered in determining the yield of agricultural crops. In this area, the beneficial effect of fertilizers, cultivation and other agricultural practices is often limited, and sometimes nonexistent, because of moisture deficiency in the soil.

The choice of rotation and the order in which the crops are rotated may largely determine the availability of moisture to particular agricultural crops under identical meteorological conditions. In the case of winter wheat, for example, it is known that the moisture availability may vary considerably according to whether wheat is preceded by clean fallow, planted fallow or stubble. Again, the moisture availability to perennial grasses under a barley cover after fallow winter crops is not the same as it is to grasses under barley after sugar beet.

Many agricultural experimental stations and institutes are engaged in research on the soil-water regime in rotation systems. In particular, a great deal of such work has been done at the experimental stations under the All-Union Scientific Research Institute on Sugar Beet (VNIS) and by the Scientific Research Institute of Southeastern Agriculture, which have already published some of their results (1, 2, 4).

In this paper, we give some of the results of our own investigations of soil moisture in grain-beet rotations in station experiments at the Draboro Experimental field.

The soils in this experimental field are thick, low-humus, coarse clay loam, coarse silt, slightly-structured chernozems. When precipitation falls, the soils readily become muddy and quickly compact after cultivation, with the result that they have a remarkably low water intake. The humus content in the arable layer varies, under different crops, from 4.2% to 4.5%.

The maximum field water capacity in the upper one and a half meter layer is, on the average, 24% to 25% or 430 or 450 mm (with a bulk density of 1.2 g/cm^3); the maximum hygroscopic moisture is 5.5%, representing, on the average, 8.2% or 150 mm of the moisture unavailable to plants. The possible available moisture content in the first meter and a half layer of the soil at maximum field water capacity is 280 to 300 mm.

Two different crop rotations were investigated in the period 1953 to 1958. The plowing-in times and the way in which the perennial grass sod was used were different in each case (Table 1). In rotation number 2, a two-year sod of alfalfa with fescue was plowed late in the fall and used under spring wheat. In rotation number 3, the sod was plowed during the summer, after the first grass-cutting, and used under winter wheat. The soil moisture was determined with a tube to a depth of 1.5 m. We shall examine the results obtained at different periods of the year.

Fall-Winter Period

The soil moisture accumulated in the fall-winter and early spring periods is, of course, more stable than is the moisture from summer precipitation. The soil holds it better and it is more fully used by plants.

Fall-winter precipitation does not thoroughly wet the entire one and a half meter layer of the soil under the conditions we are considering, except in certain very wet years. When the amount of precipitation is within the limits of the average standard calculated for a number of years, the depth of wetting does not usually exceed 60 to 120 cm. This indicates that there is no substantial loss of moisture from infiltration. In this case, the main moisture loss from fall-winter precipitation is due to surface runoff, particularly in years when the soil is deeply frozen and there is a compact ice crust on the surface.

The intensity of soil moisture accumulation in a particular rotation is determined by the character of the field's surface, the soil structure and the initial soil moisture of the upper horizons. This is, in turn, conditioned by the preceding crop, the cultivation of the soil and the weather during the preceding period.

Table 1 shows the mean values for accumulation of precipitation and available moisture in the soil of the rotation fields for a period from the beginning of winter (end of October) up to the time when work starts in the fields (first ten days of April) over the five-year period 195

Table 1

Accumulation of moisture available to plants in the top meter and a half layer of soil during the fall-winter and early spring periods. Average values for 1953-1958

Field No.	Crop	Moisture content, mm		Moisture accumulation, mm	Moisture accumulated as a % of precipitation
		Before the winter sets in	Before field work begins		
	Rotation No. 2				
1	Black fallow	98	192	94	73
2	Winter wheat	183	217	34	27
3	Barley with under cover of grass	108	192	84	66
4	Alfalfa + first-year fescue	56	134	78	61
5	Alfalfa + second-year fescue	52	107	55	43
6	Spring wheat	46	150	104	81
7	Sugar beet	97	164	67	52
8	Peas	63	137	74	57
9	Winter rye	93	142	49	38
	Average	88	159	71	56
	Rotation No. 3				
1	Winter fallow	94	187	93	73
2	Spring wheat	181	215	34	27
3	Barley with under cover of grass	111	196	85	66
4	Alfalfa + first-year fescue	57	124	67	52
5	Alfalfa + second-year fescue	52	114	62	48
6	Winter wheat	103	156	53	41
7	Sugar beet	103	168	65	51
8	Peas	63	127	64	50
9	Winter rye	94	134	40	32
	Average	95	158	63	49

Note: The mean quantity of precipitation between the beginning of winter and the beginning of field work in the spring was 128 mm.

to 1958. The quantity of atmospheric precipitation was measured at a meteorological station 300 m from the experimental plot.

As can be seen from Table 1, moisture accumulation varies from one rotation field to another. The highest percentage of precipitation absorbed occurs in a perennial grass sod plowed in fall and planted to spring wheat (81%) as well as in fields plowed and left fallow (73%). High moisture absorption is also observed in fall plowed fields, after winter fallowing and seeded to barley.

The smallest quantities of winter precipitation are used by fields of winter wheat on black fallow (27%) and winter rye (32%-33%). In certain years, the absorption of precipitation in a field of winter wheat on black fallow does not exceed 7% to 10%. This is due both to the initial soil moisture contents and to soil structure in plowed layers. As is shown by parallel investigations of soil structure, the quantity of water-stable aggregates in the turned-over perennial grass sod under these conditions amounts to 30% to 40%, whereas in black fallow it does not exceed 15% to 20%. It was clearly established in these investigations that the degree of soil wetting was inversely related to the water stability of its structure (3). The values for moisture utilization in fields of winter wheat on black fallow and on plowed perennial grass sod are evidence of the positive significance of soil structure. In the first case, the average amount of precipitation utilized was 27% and in the second case it was 41%.

In the case of rotation number 2, the precipitation utilized for the period from the beginning of winter to the time of spring field work generally averaged 56%. In rotation number 3 the average was 49%. The better utilization of precipitation in rotation number 2 is explained by the more intensive absorption of moisture in the perennial grass sod plowed in late fall and in spring wheat (field 6).

It should be noted that the values we obtained for absorption of winter precipitation seem to be rather low, because the moisture determination in the spring was made some time after the soil had thawed and therefore part of the moisture was lost in evaporation. Moreover, no allowance was made for the possibility that some moisture might have moved downward into the soil in the form of film or vapor within the meter and a half layer. Nor was allowance made for direct evaporation of winter precipitation before the soil thawed.

The breakdown by soil horizons of accumulated winter precipitation (Table 2) is of some interest. In the black fallow field, moisture penetrates deeper in the plowed perennial grass sod and in the fall plowed seeded to barley, and it is more evenly distributed among the horizons. However, in the field with winter crops on black or planted fallow it accumulates primarily in the upper half-meter layer.

The values given in Table 2 indicate that a differential approach is required in planning and applying measures for accumulating and conserving soil moisture. In particular, it is advisable to carry out snow retention first in the plowed perennial grass sod and in inversion of sod and black fallow. But the runoff of melt waters must be extensively controlled in fields bearing winter crops, perennial grasses, fall plowed fallow row crops and to a lesser extent, in plowed sod where surface runoff is negligible owing to more favorable physical soil properties.

Spring-Summer Period

It is common knowledge that this period is distinguished by a distinct predominance of moisture loss over moisture accumulation. In the black fallow field (Tables 3 and 4), despite a comparatively large quantity of precipitation, the amount of available soil moisture diminishes. In the period between the spring and the grain harvest, it decreases by 39-44 mm, while between spring and winter-crop sowing, it decreases 26-33 mm. If moisture from spring and summer precipitation is considered, the total moisture loss in the black fallow by the time grain crops are harvested is about 190 mm. In the period between spring and winter-crop seeding taken as whole, it is about 260 mm.

Under these conditions, despite established opinion, bare fallowing does not foster the accumulation of spring-summer precipitation moisture; it conserves only the moisture

Table 2

Distribution of accumulated moisture by soil horizons

Field No.	Crop	Total moisture accumulated, mm	Breakdown by horizons		
			0–50	50–100	100–150
	Rotation No. 2				
1	Black fallow	94	+47	+39	+8
2	Winter wheat	34	+26	+9	—1
3	Barley	84	+48	+34	+2
4	Alfalfa + first-year fescue	78	+52	+25	+1
5	Alfalfa + second-year fescue	55	+44	+11	—
6	Spring wheat	104	+63	+38	+3
7	Sugar beet	67	+42	+26	—1
8	Peas	74	+48	+26	—
9	Winter rye	49	+41	+10	—2
	Rotation No. 3				
1	Black fallow	93	+50	+38	+5
2	Winter wheat	34	+31	+8	—5
3	Barley	85	+44	+36	+5
4	Alfalfa + first-year fescue	67	+48	+19	—
5	Alfalfa + second-year fescue	62	+46	+17	—1
6	Winter wheat	53	+35	+16	+2
7	Sugar beet	65	+41	+23	+1
8	Peas	64	+44	+18	+2
9	Winter rye	40	+36	+8	—4

Table 3

Dynamics of available moisture for plants in the upper meter and a half layer of the soil in rotation number 2 during the spring-summer period. Mean values for 1953-1957

Field No.	Crop	Time at which observations were concluded	Moisture content		Moisture loss	Precipitation	Total moist. loss
			Before field work began	At end of period	mm		
1	Black fallow	Grain harvest	212	168	44	147	191
»	Black fallow	Winter crop seeding	212	179	33	235	268
2	Winter wheat	Grain harvest	225	64	161	147	308
3	Barley	Grain harvest	219	59	160	147	307
4	Alfalfa + first-year fescue	Second grass-cutting	154	45	109	147	256
5	Alfalfa + second-year fescue	First cutting	127	61	66	77	143
	" "	Second cutting	127	32	95	147	242
»	" "	Plowing of sod	127	26	101	235	336
6	Spring wheat	Grain harvest	161	50	111	147	258
7	Sugar beet	Grain harvest	188	96	92	147	239
»	Sugar beet	Beet harvest	188	41	147	285	432
8	Peas	Grain harvest	158	57	101	147	248
»	Peas	Winter crop seeding	158	81	77	235	312
9	Winter rye	Grain harvest	160	56	104	147	251

Table 4

Dynamics of available moisture for plants in the upper meter and a half layer of the soil in rotation number 3 during the spring-summer period. Mean values for 1953-1957

Field No.	Crop	Time at which observations were concluded	Moisture content		Moisture loss	Precipitation	Total moist. loss
			Before field work began	At end of period	mm		
1	Black fallow	Grain harvest	207	168	39	147	186
»	Black fallow	Winter crop seeding	207	181	26	235	261
2	Winter wheat	Grain harvest	224	69	155	147	302
3	Barley	Grain harvest	222	51	171	147	318
4	Alfalfa + first-year fescue	Second grass-cutting	143	40	103	147	250
5	Alfalfa + second-year fescue	First cutting	135	66	69	77	146
»	" "	Winter crop seeding	135	102	33	235	268
6	Winter wheat	Grain harvest	176	51	125	147	272
7	Sugar beet	Grain harvest	189	87	102	147	249
»	Sugar beet	Beet harvest	189	41	148	285	433
8	Peas	Grain harvest	155	53	102	147	249
»	Peas	Winter crop seeding	155	77	78	235	313
9	Winter rye	Grain harvest	157	57	100	147	247

cumulated in the fall-winter and early spring eriods, and this not completely. The main oisture losses in this period are due to evaporion; here, surface runoff in summer is neggible. In fields sown to agricultural crops, it possible to determine the total loss of soil oisture to plants from evaporation during the growing period (Tables 3 and 4). Observations were made from the time field work started in the spring.

Judging from residual moisture found in the soil at harvest, we learn that in grain-beet rotations, the crops which most dry out the soil are perennial grasses and sugar beet. In certain years, perennial grasses used for the second year take up nearly the entire moisture available by the time the sod is plowed (rotation number 2). Much the same soil-drying effect is observed after sugar beet.

When grasses are used for two years, the soil moisture deficit often makes itself felt on the successive crops (spring and winter wheat after sod and sometimes in sugar beet after plowing of sod).

The summer plowing of sod and sowing of winter wheat (rotation number 3) creates a somewhat better water regime than late fall plowing and sowing of spring wheat. The average amount of available moisture in spring under winter wheat and sugar beet in rotation number 3 (Table 1) is 4 to 6 mm higher than the moisture under spring wheat and sugar beet in rotation number 2. In particular years, however, moisture contents in spring following late fall plowing of sod and are not only conserved but even exceed the moisture contents with summer plowing, owing to fuller absorption of winter precipitation. On a five-year average (Table 1), 104 mm or 81% of the total amount of precipitation accumulates during the winter in plowed sod in late fall, and 53 mm or 41%, in all, in the sod plowed in summer.

The intensive drying of the soil under perennial grasses and sugar beet is due not only to the biological properties of these crops but also to the low initial soil moisture content of these rotation fields. If this is taken into account, the total moisture loss from all vegetation in the field of winter wheat on black fallow as well as in the field of barley is no less than the total loss in the perennial grass fields.

In the winter wheat and barley fields in rotation number 2, for example, the total decrease in moisture between spring and the grain harvest, when allowance is made for precipitation during this period, amounts to 307 to 308 mm, while the decrease in moisture in the perennial grass fields up to the beginning of the second mowing, does not exceed 242 to 256 mm. Under these conditions, the second mowing is usually made after the grain harvest.

Since we had exact values for the crop yield in our rotations, we tried to calculate and determine the total moisture loss per unit of dry crop yield in the top of the plant for different agricultural crops in rotation (Table 5).

Table 5 shows that the total moisture loss per unit dry yield of sugar beet does not exceed the moisture loss per unit yield of grain

Table 5

Total moisture loss per unit dry yield. Mean values for 1953-1957

Field No.	Crop	Yield, cntr/ha		Total yield absolute dry wt., cntr/ha	Total moist. loss during the growing period, mm	Moisture loss in weight units per unit absolute dry matter
		Grain, roots	Straw, hay, stems			
	Rotation number 2					
2	Winter wheat	19,3	58,1	66,3	308	465
3	Barley	24,2	31,2	47,4	307	648
4	Alfalfa + first-year fescue	—	42,3	35,5	256	721
5	Alfalfa + second-year fescue	—	29,7	25,0	242	968
6	Spring wheat	12,0	28,1	34,4	258	750
7	Sugar beet	270,7	126,4	88,6	432	488
8	Peas	9,9	17,4	23,1	248	1073
9	Winter rye	22,7	45,3	58,3	251	431
	Rotation number 3					
2	Winter wheat	20,3	61,2	69,8	302	433
3	Barley	22,6	28,9	44,1	318	721
4	Alfalfa + first-year fescue	—	43,8	36,8	250	679
5	Alfalfa + second-year fescue	—	22,9	19,2	146	760
6	Winter wheat	15,2	43,6	50,4	272	540
7	Sugar beet	285,2	145,2	95,4	433	454
8	Peas	8,7	19,3	23,7	249	1051
9	Winter rye	23,1	44,9	58,3	247	424

Note: Comma represents decimal point.

crops, particularly winter wheat. In second-year perennial grasses the moisture loss per unit yield is somewhat higher, owing to the relatively low yield capacity of these grasses. In the case of first-year grasses, the moisture loss per unit yield is roughly the same as it is for barley. In the field sown to peas, the moisture loss per unit yield is very high, since the yield capacity of this crop is low, owing to the frequent depredations of the pea weevil. Winter wheat after perennial grass uses moisture more economically than spring wheat.

Observations of the moisture dynamics in different soil horizons show that spring and summer losses in the black fallow field are due mainly to losses in the top half-meter layer; in the deeper layers (100 to 150 cm) there is even some increase in the quantity of moisture in comparison with the amount in spring. In land sown to peas and spring wheat, there is a decrease in the amount of moisture in the upper meter of the soil. The other rotation crops use moisture more evenly throughout the entire top one and a half meter layer.

Post-Harvest Period

Table 6 shows the dynamics of available soil moisture after the harvest. During this period, as a result of the sharp reduction in evaporation, soil moisture accumulation again begins to predominate in nearly all the rotation fields. This phenomenon is most pronounced in those fields which are freed first and are the first to be plowed in fall (the fields coming out from winter and spring wheat and winter rye). However, according to average values over a number of years the utilization of atmospheric precipitation during this period does not exceed 23% to 32%.

In fields planted with perennial grass and new sowings of winter wheat and rye, soil moisture accumulation is slight, because part of it is used up by the plants.

In conclusion, we give the data on the dynamics of soil moisture in grain-beet rotations (Fig. 1). These data indicate that the soil moisture varies considerably from season to season and from one rotation field to another, depending on the biological peculiarities of the crops and the order in which they were rotated. Specifically, the difference in moisture contents in particular rotation fields, depending on the nature of the crops, amounts to 100 mm in spring, 40 to 140 mm in summer and 30 to 130 mm in fall.

Table 6

Dynamics of available soil moisture in post-harvest period. Mean values for 1953-1957, mm

Field No.	Crop	Moisture contents in 1.5-meter layer, mm		Accumulation (+), loss (-)	Precipitation during the period	Utilization (absorption) of precipitation, %
		After harvest	Before winter sets in			
	Rotation number 2					
1	Black fallow	168	183	+15	163	9
2	Winter wheat	64	108	+44	163	27
3	Barley	59	56	—3	163	—
4	Alfalfa + first-year fescue	45	52	+7	163	4
5	Alfalfa + second-year fescue	26	46	+20	74	27
6	Spring wheat	50	97	+47	163	29
7	Sugar beet	41	63	+22	74	30
8	Peas	57	93	+36	163	22
9	Winter rye	56	98	+42	163	26
	Rotation number 3					
1	Black fallow	168	181	+13	163	8
2	Winter wheat	69	111	+42	163	26
3	Barley	51	57	+6	163	4
4	Alfalfa + first-year fescue	40	52	+12	163	7
5	Alfalfa + second-year fescue	66	103	+37	233	16
6	Winter wheat	51	103	+52	163	32
7	Sugar beet	41	63	+22	74	30
8	Peas	53	94	+41	163	25
9	Winter rye	57	94	+37	163	23

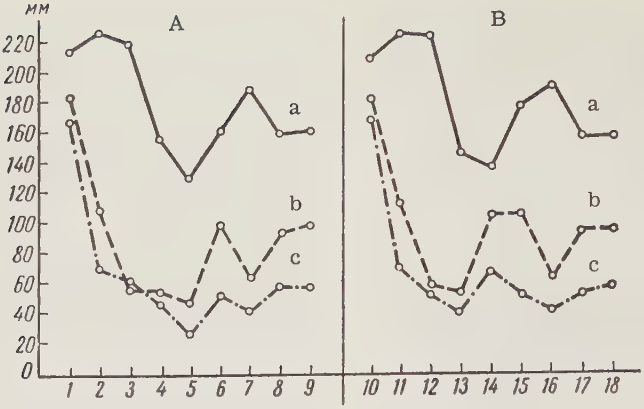

Fig. 1. - Dynamics of available soil moisture

A - rotation No. 2; B - rotation No. 3; a - before the beginning of field work; b - after harvesting; c - before winter sets in. 1 - black fallow; 2 - winter wheat; 3 - barley; 4 - first-year grasses; 5 - second-year grasses; 6 - spring wheat; 7 - sugar beet; 8 - peas; 9 - winter rye; 10 - black fallow; 11 - winter wheat; 12 - barley; 13 - first-year grasses; 14 - second-year grasses; 15 - winter wheat; 16 - sugar beet; 17 - peas; 18 - winter rye.

As seen previously, the total available moisture for crops in rotations numbers 2 and 3 is almost the same. The only important difference is that the recovery of moisture after perennial grasses with summer plowing of sod in rotation number 3 occurs gradually during the summer-fall and fall-winter periods, whereas with late fall plowing of sod in rotation number 2, this recovery is more concentrated and occurs during the fall-winter period and partly during the spring period. In dry years, however, the moisture deficit under spring wheat with late plowing of sod is greater than under winter wheat with summer plowing of sod.

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PHYSICAL PROPERTIES OF LIGHT-GREY FOREST SOILS IN THE TATAR ASSR

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Currently there is a great deal of information on the chemical composition of the soils in many of the republics, regions and provinces of the Soviet Union, including the Tatar ASSR. In many cases, on the other hand, physical properties of the soil are not studied sufficiently. This gap is particularly noticeable in regard to the eastern, Volga-Kama forest-steppe. Today, there should be no doubt that the agricultural value of soils is, in large measure, conditioned by their physical properties. It is known that certain soils which contain large amounts of various nutrient elements are not highly productive unless they have sufficiently good physical properties.

We have worked on characterizing certain physical properties of the grey forest soils (in particular, the light-grey variety) which are common in the Tatar Republic.

We shall give data for two soil profiles. One (profile 2, Michurin Collective Farm, Arskiy district) was taken from a fallow field. The other (profile 8, Baykal Collective Farm, Arskiy district) was taken from a grass field (clover and second year timothy). Table 1 gives the chemical properties of these soils.

Table 1 shows that the upper horizons of the soils investigated contain about 3.5% humus and that the humus content sharply decreases with depth. The total quantity of adsorbed cations is small; it reaches its maximum in the illuvial horizon (20 meq) and decreases appreciably in the A_2B horizon. Hydrolytic acidity is fairly high (3.35-3.95 meq H per 100 g of soil). This is reflected in the degree to which the soils are saturated with cations (79%-84%). The pH in the salt suspension indicates that there is a weakly-acid reaction in the upper soil horizon, marked acidification in the illuvial horizon and approximation to neutral in the deeper horizons. The pH of the water suspension varies similarly.

Table 1

Chemical properties of light-grey forest soils

Profile No.	Horizon	Depth, cm	Humus, %	Total adsorbed bases (meq per 100 g soil)	Hydrolytic acidity (meq per 100 g soil)	Degree of saturation with bases %	pH		P_2O_5 (Kirsanov)	K_2O (Peyve)	Hydrolyzable nitrogen (mg per kg soil)
							Salt	Water	mg per 100 g soil		
2	Ap	0—20	3,29	15,02	3,95	79,2	5,22	6,17	2,5	11,0	Not det'd.
	A_2B	20—25	0,96	9,35	3,00	75,7	4,94	5,77	4,5	8,8	
	B_1	30—40	0,50	14,95	3,50	81,0	4,49	5,74	4,75	8,8	"
	B_2	50—60	Not det'd.	20,00	3,95	83,3	4,27	5,72	5,00	7,3	"
	B_3	80—90		Not det'd.	1,57	—	5,10	6,48	20,0	5,5	"
	B_3C	120—130	"	"	0,31	—	6,59	6,76	25,0	4,4	"
	BC	145—155	"	"	0,23	—	—	7,58	—	—	"
8	A_p	0—10	3,45	17,40	3,35	83,8	6,01	6,33	7,5	11,0	85,5
	A_p	10—20	2,60	16,82	3,35	83,3	5,82	6,21	7,5	8,8	69,4
	A_2B	20—28	1,20	14,13	2,61	84,9	5,80	6,04	10,0	8,8	60,0
	B_1	28—41	0,80	18,36	4,18	81,4	5,72	5,66	15,0	8,8	Not det'd.
	B_2	41—67	0,40	20,58	4,51	82,0	5,05	5,60	18,7	8,8	

Note: Comma represents decimal point.

The available phosphoric acid content is inadequate (2.5-7.5 mg per 100 g of soil). Potassium is available in average amounts. Hydrolyzable nitrogen is present in sufficient quantity.

The data shown in Table 1 are reasonably typical of the light-grey forest soils. We may now go on to a consideration of the physical properties of these soils.

Table 2 shows the results of particle-size and microaggregate analyses. Both soils have the same texture. In both cases, the uppermost horizon is a clay-silt fine clay loam (2, 6, 7). In the transition horizon A_2B, the texture is somewhat coarser, the clay fraction here being 38%-39% against 43%-46% in the humus horizon. The texture becomes markedly finer in the illuvial horizon, especially in the B_2 subhorizon, where the physical clay fraction is 56%-65% and the clay fraction amounts to 42%-43%. The illuvial horizon must be texturally

Table 2

Particle size and microaggregate composition of light-grey forest soils (in % dry weight of soil)[a]

Profile No.	Horizon and depth, cm	Diameter of fractions, mm								Coefficient of dispersion (Kachinskiy)	Microstructureness (Dimo)
		>0,25	0,25—0,05	0,05—0,01	>0,01	<0,01	0,01—0,005	0,005—0,001	<0,001		
2	A_p 0—20	1,59 5,42	9,11 10,74	42,44 53,46	53,14 69,62	46,86 30,38	14,93 14,88	15,76 13,80	16,17 1,70	10,2	12,65
	A_2B 20—25	1,15 5,53	6,46 10,33	53,97 57,21	61,58 73,07	38,42 26,93	11,43 13,49	11,54 10,14	15,45 3,30	21,4	7,11
	B_1 30—40	0,49 4,62	10,21 24,70	35,03 46,96	45,73 76,26	54,27 23,74	10,76 11,29	10,97 8,32	32,54 4,13	12,7	26,42
	B_2 50—60	0,10 12,70	4,10 9,0	30,89 46,55	35,09 68,25	64,91 31,75	9,83 14,15	11,99 10,31	43,09 7,29	16,9	30,56
	B_3 80—90	0,48 7,37	2,00 1,05	43,44 63,88	45,92 72,30	54,08 27,70	6,90 8,72	12,25 12,31	34,93 6,85	19,6	19,49
	B_3C 120—130	0,02 2,30	16,20 17,21	48,94 64,06	65,16 83,57	34,84 16,43	4,94 6,71	9,05 7,23	20,85 2,49	11,9	16,3
	BC 145—155	— 1,78	15,50 5,92	50,91 76,91	66,41 84,61	33,59 15,39	7,38 8,27	7,45 4,99	18,46 2,13	11,5	16,42
8	A_p 0—20	0,68 3,94	8,80 12,34	47,00 56,71	56,48 72,99	43,52 27,01	16,83 16,94	12,66 8,40	14,03 1,67	11,9	13,25
	A_2B 20—28	— 2,45	8,51 19,00	51,82 57,48	60,33 78,93	39,67 21,07	8,16 9,64	12,39 8,52	19,12 2,91	15,2	16,18
	B_1 28—41	0,11 8,50	20,54 26,44	27,87 47,23	48,52 82,16	51,48 17,84	5,67 6,71	14,09 7,75	31,72 3,38	10,6	25,25
	B_2 41—67	0,11 7,06	5,65 15,62	38,22 50,61	43,98 73,29	56,02 26,71	6,56 9,50	7,51 10,39	41,95 6,82	16,2	22,36
	B_2 67—83	0,08 12,29	10,14 21,03	33,76 46,52	43,98 79,84	56,02 20,16	8,19 7,56	10,29 7,40	37,54 5,20	13,8	23,65
	B_3 83—101	0,06 0,78	9,51 19,24	46,49 68,02	56,06 88,04	43,94 11,96	6,29 5,15	8,53 4,11	29,12 2,70	9,3	31,26
	B_3C 101—111	0,01 1,17	17,18 19,47	52,74 67,52	69,93 88,16	30,07 11,84	4,58 4,94	5,41 3,91	20,08 2,99	14,9	17,07
	BC 130—140	0,01 2,88	15,33 19,41	54,33 58,92	69,67 81,21	30,33 18,79	4,89 6,90	6,28 6,64	19,16 5,25	27,4	8,67

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[a] Numerator — particle-size analysis; denominator — microaggregate analysis.

Note: Comma represents decimal point.

classified as a silty-clay coarse clay. The textural change down the soil profile indicates that the soils belong to the grey forest earth and confirms the chemical analysis. Both soils develop on a clayey-silty carbonate medium clay loam of deluvial origin containing approximately a 30% fraction of physical clay.

Table 2 also shows the microaggregate analysis data obtained by Kachinskiy's method (2, 7). The content of large microaggregates (larger than 0.25 mm in diameter) is higher in the upper horizons of the soil in the fallow field. The distribution of microaggregates with a diameter of 0.25-0.05 mm and of the total fraction of particles >0.05 mm in diameter is different in the various fields studied. These particles are more numerous throughout the entire profile of the soils under grasses, as are the microaggregates >0.01 mm in diameter. The number of very small microaggregates (<0.001 mm in diameter), on the other hand, is somewhat higher in the fallow soil. This distribution of microaggregates down the profiles of the soils analyzed entitles us to conclude that the structure-formation conditions are more favorable in the soil under grasses. This conclusion is in agreement with the observations of many investigators.

Taking the particle-size and microaggregate composition as a basis, we calculated the soil's coefficient of dispersion according to Kachinskiy's method (2). The results obtained (Table 2) show a relatively low coefficient of dispersion, varying from about 10%-12% in the uppermost horizon and appreciably increasing with depth. The very low value of the coefficient of dispersion indicates that the light-grey forest soils possess a fairly high potential capacity for structure-formation and that the main mass of particle elements in them is in an aggregated condition. When the right combination of agricultural practices is applied to these soils they will obviously become further aggregated owing to the formation of microaggregates as well as of larger aggregates.

The last column in Table 2 shows the result of calculating the microstructures of the soils according to Dimo's method.

Dimo (1) draws attention to the inverse reationship in the distribution of the clay fraction particles <0.001 mm in diameter), the coarse silt fraction (particle diameters between 0.05 and 0.01 mm) and the fine sand fraction (paricle diameters between 0.25 and 0.05 mm) obained if the soils are separated by the particle size and microaggregate analyses. She suggests that the microstructural capacity of the soils be determined by subtracting from the otal amount of the 0.05-0.01 mm and 0.25-0.05 mm diameter fractions in the microaggregate composition, the sum of these fractions n the particle-size analysis. She considers hat a comparison of the index of microstructurl capacity with the amount of clay fraction of he texture would make it possible to estimate oth the degree of microstructural capacity and he role of the clay fraction in structure-formaion. This is an interesting suggestion. Analyzng our soils from this standpoint, we see that heir clay content is in nearly every case higher han the index of microstructural capacity; that is to say, the fraction consisting of particles <0.001 mm in diameter only partially contributes to the formation of microaggregates in the soils under study. In the uppermost horizon of the soil under grasses, however, the quantity of particles <0.001 mm in diameter practically coincides with the index of microstructural capacity. In the A_2B horizon, the two values are similar, while in the same horizon of the fallow field soil, the former value is twice the latter. These findings justify the conclusion that microstructural capacity in the soil under grasses is much more intensive than in the fallow soil.

We shall now examine the results of determining the structural-aggregate composition of the grey forest soil. As can be seen from Table 3, the greatest number of structural separates >10 mm in diameter is found in both profiles in B_3 horizon, where they total 46%-54%. The following pattern is observed in the distribution of these separates. The quantity diminishes greatly from the plowed part of the A horizon (A_p) to the A_2B horizon, where they are practically non-existent. Below this, the amount of separates starts to increase rapidly, reaching a maximum in the B_3 horizon and again falling in the parent material. The content in 10-7, 7-5 and 5-3 mm diameter fractions varies in a similar way. The maximum quantity of these fractions is again found in the illuvial horizon. The smaller structural separates are distributed somewhat differently down the profiles of the soils under investigation. In the fallow soil, for example, the amount of structural separates of the 3-1 mm diameter is greatest in the A_2B horizon; the plow horizon comes next, while further down the percentage of these separates appreciably diminishes. A similar picture is observed in the soil under grasses, except that here the decrease in the amount of separates 3-1 mm diameters from horizon A_2B to horizon B_1 is considerably less abrupt and there are more of these separates in the B_1 horizon than in the plow layer. The amount of silt fractions (<0.25 mm in diameter) is greatest in the upper horizons of the light-grey forest soils and decreases sharply lower down. There is a similar variation in the quantity of separates <1 mm in diameter. The structural analysis data thus confirm the morphological characteristics of the light-grey soils. They show that the upper horizons of these soils are largely dispersed, whereas the lower horizons are made up of fairly large structural units.

We shall now consider the data for the content of water-stable aggregates in light-grey forest soils (Table 3). The upper horizons (A_p and A_2B) are characterized by a very small quantity of water-stable aggregates >0.25 mm in diameter (14%-16% for horizon A_p and 10% for the A_2B horizon), while there are practically no water-stable aggregates >1 mm in diameter. In the illuvial horizon of these soils, however, the quantity of water-stable aggregates >1 mm in diameter, like the amount of those >0.25 mm in diameter, sharply increases. In this respect, the B_2 sub-horizon stands out; whereas the quantity of water-stable aggregates >1 mm in diameter in the plow horizon does not exceed 2%-3% of the total, here it makes up 35%-40%. The content in water-stable aggregates >0.25 mm in diameter correspondingly increases to 70%. Below the B_3 horizon, the

Table 3

Structural and aggregate composition of light-grey forest soils

Profile No.	Horizon	Depth, cm	Structural composition									Aggregate composition					
			Diameter of fraction, mm														
			>10	10–7	7–5	5–3	3–2	2–1	1–0,5	0,5–0,25	<0,25	>2	2–1	1–0,5	0,5–0,25	>0,25	<0,25
2	A_p	0—20	2,6	7,7	13,0		20,9		34,7		21,1	0,2	1,3	12,5		14,0	86,0
	A_2B	20—25	0,2	2,5	10,1		32,6		18,5		36,1	0,1	0,6	9,3		10,0	90,0
	B_1	30—40	14,2	27,8	21,6	16,4	6,1	4,0	3,7	1,3	4,9	—	1,6	11,4	10,6	23,6	76,4
	B_2	50—60	19,7	27,3	23,6	19,6	5,5	2,2	1,5	0,5	0,1	18,1	17,5	27,8	8,1	71,5	28,5
	B_3	80—90	54,4	17,9	8,8	8,7	4,1	2,5	2,1	0,5	1,0	1,2	4,0	14,2	9,2	28,6	71,4
	B_3C	120—130	26,6	19,0	13,6	12,5	7,1	5,2	5,8	2,5	7,7	1,5	0,6	1,1	1,3	4,5	95,5
	BC	145—155	28,7	13,7	9,7	10,7	6,3	5,0	6,1	3,3	16,5	0,9	0,7	1,1	1,1	3,8	96,2
	C`	170—180	22,8	13,6	10,7	13,3	8,0	6,1	7,0	3,7	14,8	2,3	0,8	1,1	1,0	5,2	94,8
	C	185—195	20,0	16,5	12,4	14,7	7,8	6,1	7,1	3,9	11,5	1,8	0,8	1,1	0,9	4,6	95,4
8	Ap	0—10	14,3	7,2	8,7	12,5	8,6	8,0	10,8	6,2	23,7	1,6	1,7	5,3	4,9	13,5	86,5
	A_p	10—20	11,1	8,0	7,8	13,5	11,3	11,3	13,5	5,6	17,9	0,8	1,1	7,4	9,0	18,3	81,7
	A_2B	20—28	—	2,2	4,6	15,6	15,9	16,5	20,0	7,5	17,7	0,2	0,8	4,2	4,5	9,7	90,3
	B_1	28—41	3,5	8,8	17,0	30,8	17,6	10,9	7,8	1,7	1,9	2,1	7,8	14,8	10,0	34,7	65,3
	B_2	41—67	16,3	21,7	18,9	22,3	10,3	5,7	3,3	0,5	1,0	26,6	16,4	22,7	7,5	73,2	26,8
	B_2	67—83	23,9	24,7	17,3	16,6	7,8	4,8	3,1	0,7	1,1	7,5	9,7	21,4	11,0	49,6	50,4
	B_3	83—101	45,8	14,9	10,1	11,0	5,9	4,0	4,0	1,6	2,7	0,5	2,5	8,6	7,7	19,3	80,7
	B_3C	101—111	16,8	17,1	13,0	17,6	10,4	7,5	8,0	3,3	6,3	0,5	0,8	2,7	3,6	7,6	92,4
	BC	130—140	21,1	15,3	12,9	17,0	10,0	7,3	6,8	2,5	7,1	0,3	0,4	1,3	1,0	3,0	97,0

Note: Comma represents decimal point.

quantity of water-stable aggregates diminishes very sharply. Here, the content in particles <0.25 mm in diameter varies around 95%. It should also be noted that an appreciably large percentage of the water-stable aggregates is found in the illuvial horizon of the soil under grasses, as compared with the soil of the fallow field, whereas the upper and lower horizons of both fields are similar in this respect.

The fact that the maximum content of water-stable aggregates >1 mm and >0.25 mm in diameter are found in the illuvial horizon can, in our opinion, be explained as follows: The upper horizon is constantly subjected to mechanical influences, both as a result of man's agricultural activity (use of agricultural equipment) and as a result of atmospheric precipitation. As a result, the structure of the upper horizon is broken down. Moreover, the upper horizons of the light-grey soils are poor in the physical clay and colloidal clay fraction, owing to a fairly marked podzolization process, as is confirmed by the particle-size analysis data (Table 2). The illuvial horizon, on the other hand, is noticeably rich in the colloidal fraction. Active forms of humic acids are transported into this horizon from the upper horizon, with the result that the latter contains relatively few of these acids. New formation of active forms of humus is considerably more intensive in the soil under grasses than in the soil of the fallow field. The former's high content of water-stable aggregates confirms this. The accumulation of structure-forming substances in the illuvial horizon and the absence of factors which mechanically break down the structure in that horizon, account for the presence here of a large quantity of water-stable aggregates in comparison with the upper horizons. Below the B horizon, the colloidal clay fraction becomes much less important; there are practically no humic substances; carbonates appear in large quantity and the soil mass becomes structureless.

The parent material horizons, which under field conditions appear structured, since they have fairly pronounced nutty-blocky units, are, in fact, structureless; the amount of water-stable aggregates in them does not exceed 5%.

We will now look further into the physical properties of the soils under study. These are given in Table 4, starting with particle density. The particle density for the solid phase in the upper horizon of the light-grey soils varies round 2.6 g/cm³, increasing with depth to 2.70-2.75 g/cm³. These characteristics are present in the soils of both profiles. The particle density of the soil skeleton or its bulk density varies somewhat differently. In the upper horizon of the fallow soil, the bulk density is only 1.08 g/cm³. Lower, it rapidly increases and varies around 1.5 g/cm³. In the upper horizon of the soil under grasses, the bulk density is considerably above that in the same horizon of the fallow soil, amounting to 1.25-1.29 g/cm³, although further down the profile the bulk density increases to a negligible extent. Such a variation in the bulk density of these soils indicates that the upper horizon of the fallow soil is very loose, whereas the lower horizons are appreciably compacted. Some compacting is observed in the upper horizon of the soil under grasses, while the lower horizons are characterized by appreciably less compacting in comparison with the corresponding horizons of the fallow field. This shows that the well-developed, highly-penetrating root system of the grasses, while to some extent binding the topmost, humus horizon, loosens the lower horizons, improving the soil consistence and making it more permeable by air and water.

The bulk density figures agree with the results obtained from determining the soil compactness or hardness by means of Kachinskiy's penetrometer (5). In the plow layer of the fallow soil, for example, the compactness is 5.16 kg/cm², whereas in the upper horizon of the soil under grasses, it is 7.73 kg/cm², or one and a half times higher. In the lower horizons of the first soil it is 11 kg/cm², whereas in the corresponding horizons of the second soil it varies around 5-7 kg/cm². The compactness of the soil under grasses throughout the entire profile is, thus, more uniform and considerably less than in the soil of the fallow field. This once again underlines the favorable effect of perennial grasses on the physical properties of grey forest soils.

We were the first to determine the differential porosity of the light-grey forest soils of the Tatar Republic by Kachinskiy's method (3, 4). Table 4 shows that in the fallow soil the total porosity reaches a fairly high value, varying between 54% and 60%. In the field under grass, particularly in upper part of the humus horizon, the total porosity is nearly 10% lower than in the first soil. Starting from the illuvial horizon, the porosity in the fallow soil decreases comparatively rapidly and is only 33% at a depth of 140-150 cm. But in the soil planted to perennial grass porosity varies around 50% to a depth of 140 cm, and scarcely alters throughout the profile.

Thus, both the total porosity value and the change in porosity down the profile are more favorable in soil under perennial grasses. The large volume of pores in the plow horizon of the fallow soil makes for appreciably more intensive aerobic processes which step up the mineralization of organic matter. At the same time, it lowers the water-retaining capacity of this soil. The water-air properties deteriorate in the lower part of its profile, owing to the fairly rapid reduction in total porosity with depth. In the second soil, the constancy of the total porosity value down the profile ensures a more favorable air-water regime.

A discussion of the differential porosity allows consideration of the degree to which the soil pores fill up with various forms of water and air. We find that the volume of pores occupied by capillary water is considerably greater in the humus horizon of the soil under grasses, varying around 60% of total porosity, whereas in the corresponding horizon of the fallow soil it is 36%. In the transitional A_2B horizon these values are similar in each field (41%-46%). In the upper part of the illuvial horizon, the fallow soil has an appreciably larger share of pores occupied by capillary water; lower down, both soils become equal in this respect.

The quantity of pores occupied by loosely-

Table 4

Physical properties of light-grey forest soils

Profile No.	Horizon	Depth, cm	Density		Compaction (kg/cm²) (hardness)	Porosity										
			Particle	Bulk		Total	% of soil vol. comprised by pores occupied by					% of total porosity comp. by pores occ. by				
							Water				Air (capillary saturation)	Water				Air (capillary saturation)
							Capillary	Loosely-combined	Firmly-combined	Total		Capillary	Loosely-combined	Firmly-combined	Total	
2	$A_п$	0—20	2,62	1,08	5,16	58,78	21,15	2,62	4,38	28,15	30,63	36,00	4,46	7,44	47,90	52,10
	A_2B	20—25	2,68	1,22	9,03	54,48	25,23	2,67	4,46	32,36	22,12	46,40	4,90	8,40	59,70	40,30
	B_1	25 45	2,72	1,45	10,95	46,69	16,40	6,10	10,11	32,61	14,08	35,12	13,06	21,65	69,83	30,17
	B_2	50—60	2,70	1,48	10,95	45,00	8,80	6,45	14,42	29,87	15,13	19,55	14,78	32,04	66,37	33,63
	B_3	80—90	2,67	1,52	6,65	43,07	9,67	7,48	12,30	29,45	13.62	22,44	17,40	28,60	68,44	31,56
	B_3C	120—130	2,74	1,54	6,20	43,80	20,33	4,94	8,23	33,50	10,30	46,43	11,46	18,70	76,59	23,41
	BC	145—155	2,70	1,80	9,40	33,34										
8	$A_п$	0—10	2,55	1,29	7,73	49,40	28,35	3,14	5,23	36,72	12,68	57,40	6,35	10,59	74,34	25,66
	$A_п$	10—20	2,59	1,25	6,70	51,74	32,99	2,50	4,17	39,66	12,08	63,76	4,83	8,06	76,65	23,35
	A_2B	20—28	2,68	1,31	7,20	51,12	21,25	3,84	6,40	31,49	18,63	41,57	7,51	12,52	61,60	38,40
	B_1	28—41	2,64	1,32	7,33	50,00	9,32	6,10	10,17	25,59	24,41	18,64	12,20	20,34	51,18	48,82
	B_2	41—67	2,75	1,30	6,13	52,73	4,97	7,55	12,58	25,10	27,63	9,43	14,13	23,86	47,42	52,58
	B_2	67—83	2,65	1,31	4,80	50,00	14,93	6,62	11,05	32,60	17,40	29,86	13,24	22,10	65,20	34,80
	B_3	83—101	2,67	1,34	4,13	49,80	19,39	5,69	9,49	34,57	15,23	39,00	11,42	19,05	69,47	30,53
	B_3C	101—111	2,70	1,35	5,70	50,00	21,44	2,95	4,93	29,32	20,69	42,88	5,90	9,86	58,64	41,36
	BC	130—140	2,70	1,36	5,47	49,60	31,43	2,78	4,65	38,86	10,74	66,37	5,60	9,37	81,34	18,66

Note: Comma represents decimal point.

combined water in the upper horizons of the two soils varies around 5% and 6%, respectively, increasing to 12%-17% in the illuvial horizon. The amount of pores occupied by firmly-combined water varies around 7%-10% and 20%-30% of total porosity, respectively; in other words, it is one and a half to twice the quantity of pores occupied by loosely-combined water. The sum of pores occupied by both forms of combined water shows that the upper horizons of the two soils are similar in this respect. In the illuvial horizon, however, the fallow soil has the greater total quantity of pores occupied by combined water. The deeper horizons of this soil are consequently somewhat less easily penetrated by air than those of the second soil.

When we compare the upper horizon of the two soil profiles in respect to the quantity of pores occupied by air when the soil is saturated with capillary water, we find a very great difference between the two soils (last column of Table 4). In the fallow soil, these pores account for 52% of total porosity, whereas in the soil under grasses they make up only 25%. The only explanation for so great a difference must be that the upper, strongly aerated horizon of the first soil has greater cavities between the large clods formed during plowing. These cannot retain water and are occupied by air; there are hardly any such clods in the upper horizon of the soil under grasses. In the A_2B horizon, the percentage of such pores is similar in both soils, whereas lower down (within the top meter layer), the grass-field soil has the greater quantity of pores occupied by air. This once again confirms that the latter soil has better water and air permeability throughout its entire profile.

The figures on differential porosity of the soils show that the upper horizon of the soil under grasses retains more capillary water which is highly available to plants, while the aerobic processes occur here somewhat less intensively than in the plow horizon of the fallow soil. On the other hand, better water and air permeability within the topmost meter of the profile is observed in the first soil. All this confirms the fact that perennial grasses have a favorable effect on the structure of light-grey forest soils.

In conclusion, let us consider the moisture properties of these soils. Table 5 shows that the variation in field moisture (moisture at the moment of working) within the profile varies according to whether it is expressed as weight or volume percentages. In the fallow soil, the amount of field moisture expressed as weight percentages gradually decreases with depth, whereas if it is expressed in volume percentages

Table 5

Moisture properties of light-grey forest soils

Profile No.	Horizon	Depth, cm	Field moisture %		Moisture capacity, %			Maximum hygroscopicity %	Coefficient of wilting moisture, %	Active range of moisture	Moisture content retained by the soil, mm[b]			
			Weight	Vol.	Total	Capillary	Cap. as % of total				Maximum		Active	
2	A_p	0—20	26,00	28,08	30,0	28,7	95,7	6,08	9,12	19,58	61,99	420,50	42,29	150,57
	A_2B	20—25	22,27	27,17	34,8	28,9	83,0	5,48	8,22	20,68	17,63		12,61	
	B_1	25—45	23,44	33,99	28,2	27,1	96,1	10,53	15,79	11,31	78,59		32,80	
	B_2	45—70	24,83	36,75	29,6	28,1	94,9	14,62	21,95	6,15	103,97		22,28	
	B_3	70—112	22,20	33,74	27,6	24,8	89,0	12,29	18,44	6,36	158,32		40,59	
	B_3C	112—133	22,40	34,50	26,7	25,2	94,3	8,02	12,03	13,17	82,50	156,86	42,59	81,51
	BC	133—150	20,77	37,70	24,8	24,3	98,0	7,72	11,58	12,72	74,36		38,92	
8	A_p	0—10	12,75	16,45	34,4	31,1	90,4	6,08	9,12	21,98	40,12	375,54	28,38	161,27
	A_p	10—20	13,26	17,10	35,3	33,3	93,8	5,01	7,51	25,59	41,37		32,00	
	A_2B	20—28	15,90	20,83	32,6	27,2	83,4	7,33	10,99	16,21	28,51		17,00	
	B_1	28—41	19,55	25,81	28,1	24,4	86,8	11,56	17,34	7,06	41,97		12,11	
	B_2	41—67	24,35	31,65	30,2	25,6	84,8	14,52	21,78	3,82	86,53		12,91	
	B_2	67—83	27,16	32,86	36,1	30,4	84,2	12,65	18,97	11,43	63,72		23,96	
	B_3	83—101	23,01	26,23	35,3	30,4	86,1	10,62	15,93	14,47	73,32		34,91	
	B_3C	101—111	19,41	26,10	29,1	24.1	82,8	5,48	8,22	15,88	32,53	195,89	21,43	144,00
	BC	111—150	18,36	21,21	35,0	30,8	83,4	5,13	7,69	23,11	163,36		122,57	

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[a] Calculated as 1.5 maximum hygroscopicity.

[b] By horizons and by layers (topmost meter and next half-meter)

Note: Comma represents decimal point.

the opposite is true, that is, it increases with depth. This is due to the great increase in bulk density of this soil with depth. In the soil under grasses, we find that the variation in both values is correlated; this is due to the stability of the bulk density in the soil profile. It is not possible to compare the absolute values for moisture in the two soils, since the profiles were taken at different times (an interval of two weeks).

The results of determining the moisture capacity of the light-grey forest soils show that the maximum moisture capacity in these soils is not high; in the upper horizons of both soils it is 30%-35% and decreases slightly with depth in the fallow soil, remaining more stable in the soil under grasses. The relatively low value for moisture capacity in these light-grey soils can be explained by their low humus content (about 3.0%-3.5%) and large silt fraction.

Similar figures were obtained for the capillary moisture capacity. Certain variations in the values for maximum and capillary moisture capacity within the profiles of both soils are obviously due to variations in the texture and structure. The relationship between maximum and capillary moisture capacity in the light-grey forest soils is interesting. In the profile of the fallow soil, the capillary moisture capacity is about 95% of the total moisture capacity. The A_2B horizon, where it is 83%, is the only exception. In the soil under grasses, this relationship varies, although to a negligible extent. In the upper horizon, the capillary moisture capacity is 90% of the maximum, whereas in the rest of the profile it varies around 83%. Such a ratio between maximum and capillary moisture capacity is unfavorable; it shows that capillary porosity is strongly developed in light-grey forest soils, whereas the non-capillary spaces occupy only a restricted volume. This is confirmed by the aggregate analysis data, which show that they are considerably dispersed and lack a water-stable structure. The soil occupied by a grass mixture, is better in this respect to some extent.

Maximum hygroscopicity in the light-grey soils reaches its highest value in the illuvial horizon, which is rich in the clay and, particularly, the colloidal fraction. The coefficient wilting moisture as calculated from maximum hygroscopicity (1-1/2) varies accordingly.

Table 5 also gives the results of the "active moisture range" of light-grey forest soils. Kachinskiy (4) uses this term to mean the difference between the total moisture capacity of the soil (similar to the "capillary moisture capacity" of many authors) and the wilting percentage. This value is an important characteristic of the soil, since it shows the degree of availability of soil moisture and the capacity of the soil to meet the water demands of plants. If the active moisture range is small, plants growing in the soil will suffer from water deficiency. On the basis of much experimental information, Kachinskiy concludes that this deficiency may occur if the "active moisture range" is below 20, whereas if it is higher than 20, favorable conditions will be created.

Our figures show that more favorable conditions for the satisfaction of the plants' water demands will be created in the upper horizon (0-20 cm) in soils under grass than in the corresponding horizon of the fallow soil. In the former, the active moisture range is 22%-25%, whereas in the latter it is only 19%. The "active moisture range" decreases abruptly in the illuvial horizon of both soils, since soil moisture in this horizon is combined and passes into a form unavailable to plans owing to the accumulation of a large quantity of finely-disperse particles in this horizon. The water regime of light-grey forest soils is consequently unfavorable to the vital requirements of plants from a depth of about 30 cm downwards.

The last two columns of Table 5 show the results of calculating the maximum (in terms of capillary moisture capacity) and the available or active (in terms of the active moisture range) water contents held by the soil, both for the individual horizons and also for the topmost meter and next half-meter of the profile, expressed in mm.

Comparison of these figures shows that in the upper meter layer of both soils a large quantity of water is retained (375-420 mm). The soil under grasses, however, retains a greater quantity of available water (161 mm) in this layer compared with the fallow soil (150 mm). This pattern is still more marked in the meter-and-a-half layer — 144 for the first soil and 81 mm for the second. The calculations of available moisture held by light-grey forest soils thus once again illustrate the beneficial effect of perennial grasses on the physical properties of these soils.

Conclusions

1. The physical properties of light-grey forest soils are unfavorable. These soils are poor in humus, adsorbed cations and available phosphorus. They are characterized by a strong predominance of capillary porosity over non-capillary, and consequently by poor water and air permeability. The upper horizons of these soils are strongly dispersed, with the result that they are subject to erosion. On the other hand, microstructure is sufficiently pronounced in these soils. They contain potassium and have a weakly-acid reaction.

2. In order to improve the physical properties of light-grey forest soils, it is necessary:

a. to seed perennial grasses in field rotations on these soils. This will foster structure formation, enhance water and air permeability, increase the availability of water in the soils and the accumulation of ash element and humus;

b. to build up a thick cultivatable layer by turning up part of the A_2B (or $B_1{}^1$) towards the upper horizon and at the same time introducing organic fertilizers and lime. This greatly enhances the productivity of these soils, making them less subject to dispersion, more permeable to water and air and better able to retain precipitation, with the result that their yield in agricultural crops greatly improves;

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c. to apply both organic and mineral fertilizers in order to improve the nutrient status in these soils.

3. In light-grey forest soils, forest windbreak, which is a powerful factor in controlling erosion, or buffer strip of perennial grasses should be planted crosswise on the slopes.

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EFFECT OF FROST ON THE STRUCTURE AND EROSION RESISTANCE OF THE SOIL IN RELATION TO ITS MOISTURE

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The study of soil structure stability is interesting in connection with the problem of working out the theoretical principles of the soil's resistance to erosion.

The upper layer (15-20 cm) is the most active zone in the soil profile. In this layer variations of temperature, moisture, and the content and composition of soil air are most pronounced and extensive. Although the structural condition of the soil also varies considerably in the course of the year, the majority of the data on structure given in the literature refer to the warm period.

There has been sufficient study of the mechanics of frozen soil and the processes which occur when the soil is freezing or thawing, including the influence of suitability of the ground for these processes on the building purposes (4, 5, 6, 12, 14, 15 etc.), but there have not been many papers discussing how freezing of the soil affects agricultural production. Here we must mention the work of Kostychev (11), Vil'yams (3), Kachinskiy (7), Koloskova (8, 9, 10), Vershinina (2), and Baruskova and Bakharevaya (1), as well as the works of such foreign authors as Wollny (29), Ehrenberg (20), Bouyoucos and McCool (17), Baver (16), Russell (25), and Mitscherlich (24), including recent publications by Gardner (21), Salter and Hopp (22, 26, 27, 28), Chapil (18), Domby and Kohnke (19), and Koepf (23).

From the work of these authors, we may conclude that the influence of frost on the soil's structural condition and erosion water-stability has been little studied so far and that recurrent frost and thaws unquestionably influence the structural formation of many soils; a definite "cryogenic" (frozen) structure occurs under certain special conditions. The nature of this structure depends not only on the soil temperature and on the thickness and effectiveness of the insulating layer (snow, mulch), but also on the properties of the frozen soil itself (particle size and mineralogical composition, organic matter content, moisture content in the frozen soil and subsoil, nature of the soil solution and composition of adsorbed cations and other factors). Under natural conditions, obviously, there can be various combinations of these factors, which interact in a complicated manner. When investigating this question, therefore, it was particularly important to use a method which would permit strict isolation of one factor in the experiments, all other values remaining constant. The method had to allow for working with undisturbed soil samples while at the same time ensuring that structural changes occurring in the soil under the influence of freezing could be recorded with sufficient reliability.

After examining a number of methods proposed by various authors for studying the soil structure and determining the aggregate stability, we decided on the Fadeyev-Vil'yams method with Pustovoitov modification based on the principle of the movement of water through a soil column (13). Pustovoitov's apparatus makes it possible to determine the water stable structure in undisturbed soil samples.

In all experimental treatments, the variable was the moisture content in the soil sample. The depth and horizon from which the sample was taken, as well as the conditions under which the experiment was conducted (namely the mass and volume of soil, the temperature, the duration and conditions of freezing, the water head in determining the coefficient of percolation) remained strictly constant. The size of the soil sample was conditioned by the dimensions of the bearing cylinder of the instrument, the height and inside diameter of which were 75 mm. Using such cylinders as drilling tools, we took undisturbed samples from a horizontal monolith of peaty-gley soil (Amur region) in A_1 horizon at a depth of 15-25 cm. In texture, the soil is silty-sand clay loam with a physical clay content of 37.2% including 14.8% clay. At this depth, the quantity of humus, as determined by Knop is 2.03%. Ca^{++} (24.31 meq) predominates in the composition of the adsorbed cations, followed by Mg^{++} (2.14), Na^{+} (0.73) and finally H^{+} (0.48).

Soil samples in the cylinders were brought to the required moisture content, sealed with thin commercial rubber and then quickly transferred to a chamber kept at a constant temperature of 8-10°C below zero. In all experimental treatments, freezing lasted for 72 hours. After freezing, the samples were thawed at room temperature. By the time these samples had thawed completely, control samples had been prepared which were not frozen. Up to the time of the experiment these had the same moisture content as the samples subjected to freezing action for 72 hours. The samples were placed in a percolation apparatus and the percolation readings were taken simultaneously for the experimental and the control samples over fixed time intervals until constant values for these quantities were obtained. The coefficient of percolation when the temperature of the water was +10°C was then calculated.

The stability of the soil structure was estimated indirectly from the manner in which the percolation decreased. It is known that a fairly-large and stable amount of percolate per unit time is characteristic of soils with a stable structure, whereas a small amount of percolate and a rapid drop in the percolation are characteristics of stable, structureless soil. The percolation was repeated three and, in some cases, four times. The effect of freezing by thawing on the soil structure was studied, the soil moisture being equal to field capacity at 60% of maximum moisture capacity. A variation of the experiment, in which the soil was frozen in a chamber under conditions of optimum moisture (60% of total moisture capacity) was repeated and the soil samples were brought o an air-dry condition after thawing at room emperature; in the case of aggregate fractions of 5-7 mm in diameter, the porosity was determined.

At the end of the fifth hour of observation he percolates both from the soil samples which had been frozen in the chamber and rom the control samples which had not been rozen were collected. The optical density of the filtrates was determined in a photoelectric colorimeter-nephelometer. This gave ndirect information on the influence of freezing on the colloidal soil complex.

A brief review of the results obtained folows. By the end of the fifth minute from the start of the observations, the percolation of he excessively wet frozen sample in thawed condition decreased by a factor of 1.7 in comparison with the control sample (Table 1). However, by the end of the first hour it had allen to one-third of the quantity from the unrozen soil. After thawing, the frozen soil n the excessively wet state was less stable o the leaching action of water: its waterermeability by the end of the first hour was .5 times less than at the beginning, whereas he water permeability of the control sample, n which the moisture content before leaching ad been the same, diminished by a factor of ess than five. It follows that in the process of reezing and thawing, excessively wet soil (soil vetted fully or almost to field capacity) quickly oses the stability (water stable) of the soil tructure which it had before freezing; its water ermeability decreases appreciably.

Diametrically opposite results were obtained y freezing the samples with optimum moisture ontent (60% of maximum moisture capacity, able 1). In this treatment, the percolation of he control samples decreased by the end of the irst hour to one-sixth (from 1.79-0.29 mm per ninute), and by the end of the third hour to oneixteenth (from 1.79-0.11 mm per minute) in omparison with the initial value. However, in he case of the frozen samples the corresponding

Table 1

Influence of freezing on the structural conditions of the soil in relation to its moisture. Peaty-gley soil, A_1 15-25 cm

Soil moisture, in %, before freezing in chamber		Duration and temperature of freezing	Observation intervals, minutes															
			5	5	5	5	10	10	10	10	30	30	30	30	60	60	60	60
			Coefficient of percolation, mm/min at 10°C															
Field capacity	68,3	Without freezing (control)	1,16	1,20	1,07	0,83	0,77	0,43	0,31	0,25	0,17	0,13	0,13	Not det'd.				
60% of maximum moisture cap.	70,8	72 h at -8° to 10°C	0,68	0,70	0,58	0,47	0,23	0,17	0,13	0,08	0,07	0,07	0,07					
	24,5	Without freezing (control)	1,79	1,71	1,68	0,94	0,60	0,34	0,29	0,29	0,22	0,18	0,15	0,11	0,11	0,11	Not det'd.	
	25,1	72 h at -8° to -10°C	3,35	2,65	1,88	1,55	1,15	1,01	0,86	0,81	0,72	0,66	0,59	0,58	0,57	0,56	0,54	0,51

Note: Comma represents decimal point.

reduction over the same periods was one-fourth and one-sixth of the initial rate (3.35 mm per minute), respectively. By the end of the first hour, the percolation of the control samples was roughly one-third and by the end of the third hour, one-fifth of the values for the frozen samples. Soils frozen at optimum moisture (in this case 60% of maximum moisture capacity) and tested in the thawed condition, accordingly show some increase in the water permeability and water stable aggregates, which are retained throughout the entire period of the experiment, in comparison with unfrozen soil at the same moisture content.

In the freezing process, the colloidal fraction in the soil is fixed. The optical density of the percolate from the unfrozen soil sample is almost six times greater than that of the frozen sample. The precipitation ("denaturing") of the colloidal, most active fraction of the soil, which is rich in humus and nutrients, on to the surface of the mineral elements increases their potential capacity for adhesion, which under the particular conditions of freezing causes a rise in the water stable soil structure.

The porosity determination of the 5-7 mm diameter aggregates showed that under optimum moisture conditions freezing led to a 13% reduction of porosity in comparison with the original soil (Table 2). This can be explained by the consolidation and compression of the soil mass by crystals and lenses of ice forming in the soil while it is freezing. These form primarily in the non-capillary and large capillary pores. At the same time, as field investigations have shown, in almost all cases freezing is accompanied by a more or less considerable increase in the total porosity and decrease in the bulk density of the soil (Table 2). The increase in water permeability resulting from freezing (in the case of optimum moisture) can thus be explained by increased porosity between the aggregates and increasing water stable soil structure. In excessively wet soils, the soil particles show no definite structural coherence on freezing. Conversely, the freezing of the excess water, in particular in cases where it flows readily and freely towards the freezing front from the still unfrozen underlying soil horizons, causes rupture or crushing of the aggregates, with the result that the soil turns into a structureless mass after thawing.

On the basis of the laboratory and field observations, the following conclusion can be drawn: Soils which enter the winter in an excessively wet condition (or in cases where the capillary fringe zone, which makes the free flow of moisture to the freezing layer possible, is near the freezing layer) will, other conditions being equal, suffer from water erosion during the optimum range of moisture content when they freeze. Field observations show that in cases where the capillary fringe zone is near the surface, such methods as banking up the winter plow-land so as to reduce the spring surface runoff due to "runoff" within the soil are not very effective since by the time the thaw sets in, such soils are not capable of absorbing extra quantities of water, being already thoroughly saturated. In these cases, measures to regulate the snow thawing must be recommended.

Table 2

Influence of freezing on total porosity of soil and porosity of aggregates

Peaty-gley soil

Horizon	Depth, cm	Moisture %	Method of preparing the soil	Porosity of fraction of particular aggregates (%)	Bulk density of aggregates
A_1	15—25	24,0	Freezing for 72 h at -8° to -10°C	40,45	1,56
			Without freezing (control)	53,62	1,09

Sod-meadow soil

Horizon	Depth, cm	Total porosity in % as determined	
		As thawed on Aug. 5, Aug. 9, Aug. 29, 1954	October 1, 1954
A	0—4	77,21	74,26
A_1	15—19	65,03	56,39
B	28—32	61,79	Not det'd.
I layer	50—54	59,70	50,37
II "	90—94	61,27	46,99
III "	166—170	59,77	Not det'd.
III "	200—204	62,79	43,79

Note: Comma represents decimal point.

In connection with soil erosion investigations, it is essential to find the hydrological conditions of soil formation so as to be able to forecast more accurately the effectiveness of erosion control measures as applied to soils which are freezing, because of the change in their resistance to erosion and water permeability.

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GENESIS OF THE SECOND HUMUS HORIZON IN THE GREY FOREST SOILS OF THE KRASNOYARSK REGION

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When soils have a second humus horizon, there is, in addition to the top humus horizon A_1, a dark colored horizon A_h (second humus) at a certain depth, separated from the A_1 horizon by a light podzolized horizon A_2. Most investigators regard podzolization in these soils as the final stage in their formation and regard the second humus horizon as a relict of an earlier process of soil formation.

During the last 50 years, soils with two humus horizons have been found in various parts of the Soviet Union. Such soils are particularly common in the West Siberian depression where the southern taiga joins the northern forest-steppe (on flat valleys between rivers and old terraces).

Soils with a second humus horizon were first discovered in 1895 by Gordyagin (4) in the former Tobolsk district. A number of investigators have recently described such soils found in various places in Western Siberia (16, 10, 12 et al.). A great contribution was made by Dranitsyn (8), who was the first to make a detailed investigation of the genesis of the second humus horizon. Later work was done by Glinka (6), Gorshenin (5), and Petrov (15), as well as Ivanova and Dvinskikh (9), who added much to our picture of the genesis of the second humus horizon. Dolgova (7) gave a detailed description of such soils.

At present there are four hypotheses in regard to the genesis of such soils: 1) the degradation of chernozems owing to forest invasion of steppe-lands (10, 5); 2) podzolization of flood plain dark-colored soils (8, 12, 15), meadow-chernozem or chernozem-meadow soils (14, 9) or solodization of salinized soils (9); 3) podzolization of meadow-bog soils as a result of intensified drainage (6); 4) a contemporary process of soil formation in the grey forest soils, characterized by migration along the profile (illuviation) of acid calcium humates, which have not been completely neutralized, and their deposition at some depth in the form of fully saturated Ca and R_2O_3 humates (16).

Soils with a second humus horizon have been detected in the Krasnoyarsk region by Petrov (14), and Kolyago (11). Both investigators regard the second humus as a relict. They differ in that Petrov regards the formation of this horizon to be the result of a change from one soil-forming process to another owing to changing climatic conditions, whereas Kolyago believes it to be the result of mechanical burying of the humus horizon by deluvial-proluvial deposits.

In this paper, we shall give a short account of the characteristics of soils with a second humus horizon in the Pirovo district of the Krasnoyarsk region. Field research by the Soil Division[2] has established that grey forest soils with a second humus horizon extend along the boundary of the northern forest-steppe and the southern taiga. This region is on the eastern border of the West Siberian depression between 57 and 58° N and 91 and 93°E. To the east, this region adjoins a slight rise in the Kem-Yenisei plain and constitutes a watershed between the Kem and Ket Rivers. This is a gently-rolling plain sloping, as a whole, northwards. The parent material for these soils is made up of clay and loam Quaternary deposits a few meters to several tens of meters thick (11). The climate is continental, with cold winters and warm summers. Annual precipitation is 380 mm, 300 mm of which falls during the frost-free period. The soil freezes for 5-7 months of the year and at a depth of about 1 m the seasonal frost disappears only in the middle of June. Geobotanically the region belongs to a transition belt between the northern forest-steppe and the southern taiga. The forests are pine, beech and aspen, often with spruce, fir and cedar. The density of the low-growing vegetation depends on the density of the forest and consists of reed grass, meadow-rue, raspberry, meadow grass and pea vine with admixtures of fireweed, vetch, and burnet. Mosses are found in shady areas.

We have called the soils formed here grey forest medium podzolic with a secondary humus horizon. These soils have the following pro-

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[1] The paper gives the characteristics of soil within the Pirovo district.

[2] Ye.N. Ivanova and A.A. Yerokhina, of the staff of the V.V. Dokuchayev Soil Institute, USSR Academy of Sciences, directed the work of the Soil Division in the Krasnoyarsk territory.

file: humus horizon A, grey or light-grey, 15-20 cm thick, densely penetrated by roots to a depth of 5 cm, marked transition to next horizon; horizons A_1, A_2, clearly podzolized, light-grey, whitish, 12-17 cm thick; second humus horizon A_h at a depth of 30-40 cm, dark-grey with coal-like shading, indistinct nutty-blocky structure, thickness 30-50 cm, well marked transition to B_1 horizon, which at 80-100 cm gives way to brown cinnamon-brown gleyed horizon B^g_2; this, in turn, gives way to a structureless yellow-brown clay at a depth of 115 cm. The soil does not effervesce until a depth of 180-200 cm is reached. The second humus horizon throughout the whole territory investigated is a dark fringe at a depth of 30-100 cm, very distinctly separated from the A_1 horizon by the podzolized A_2 horizon. Its upper boundary lies a good deal above the residues from the stratum of prolonged seasonal freezing (90-100 cm).

Despite the pronounced morphology, the second humus horizon can be analytically detected only by its humus content. It has, in general, all the properties of this genetic horizon of contemporary soil-forming processes, with which, as regards its position in the profile, it coincides. In most cases, the second humus horizon either coincides with B horizon of the recent profile, or is situated somewhat higher than this. The "hidden" chemical property of the second humus horizon has been noted by many authors (1 et al).

As Table 1 shows, the soil has a clayey-silty texture. The lower horizons are notably rich in clay, but this is not transported out of these horizons. The humus content is high (about 8% in horizon A_1). The extended humus profile is characteristic; even at a depth of about 1 m the humus content does not fall below 0.8%. There is an acid reaction throughout the profile. The variation in total adsorbed cations corresponds to variation in texture. Horizon A_1 is an exception; here, the total number of adsorbed cations is high because of the considerable humus content.

The adsorption soil complex is saturated mainly with calcium which varies between 68% and 89%. There is little exchangeable hydrogen, as determined by the Gedroyts method. Hydrolytic acidity in the upper part of the profile is high but decreases appreciably with depth. The distribution of total iron content confirms that illuviation is taking place in the profile. Total chemical analysis of the soil (Table 2) reveals a relative accumulation of SiO_2 in the podzolized upper horizons, from which there is a loss of sesquioxides and calcium. The A_h horizon, for example, can be detected in the profile only through its humus quantity, which is greater here than in the A_1 and A_2 horizons (Table 3). This fact bears out the morphological separation of the second horizon. From the intensity of its color, one would, of course, expect a higher humus content in this horizon; the upper humus horizon contains 8.2% humus and has a dark-grey color, whereas the lower humus horizon contains altogether 2.9% humus and has a black color. The explanation, noted by many authors (20 et al.), seem to be that the humus compounds are of a different kind in the upper and lower horizons.

Determinations of the group composition of the humus showed that, in this respect, both the upper horizons (A_1 and A_1A_2) are quite distinct from the second humus horizon A_h (Table 4). In the upper horizons, the ratio of C (humic acid): C (fulvic acid) is 1.2 and 1.3, which is characteristic of forest-steppe and forest soils. The ratio of C (humic acids): C (fulvic acids) in the second humus horizon

Table 1

Particle-size analysis of soil by Kachinskiy method (% absolute dry weight)[a]

Profile No.	Horizon	Depth, cm	Hygroscopic moisture	Losses on treatment with HCl	Percentage of particle diameters, mm						Total part. <0.01 mm in diam.
			in percentages		1,0−−0,25	0,25−−0,05	0,05−−0,01	0,01−−0,005	0,005−−0,001	0,001	
89	A_1	9—14	4,38	2	2	6	30	16	13	31	60
	A_1A_2	20 −25	3,68	2	2	4	32	13	19	28	60
	»	27—32	3,63	2	1	11	29	14	15	28	57
	A_h	40—45	4,09	2	1	6	29	13	16	34	63
	»	65−70	5,35	3	1	2	28	9	14	43	66
	B_1B_2	95 100	5,62	3	1	0	28	8	16	44	68
	C	145—150	5,04	3	1	0	23	13	16	44	73
50	A_1	2−7	Not det'd.	1	0	1	31	16	22	29	67
	A_1A_2	7—17	"	1	0	1	31	15	21	31	67
	A_h	30—35	"	0	0	0	37	8	20	35	63
	B_1B_2	70−75	"	0	0	0	31	10	19	40	69

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[a] The analysis was performed in the chemical laboratory of the State Municipal Building planning Institute (Giprokommunstroy. Analyst — M. I. Baklushina).

Note: Comma represents decimal point.

Table 2

Total chemical analysis of soil (%) humus-free absolute dry weight

Profile No.	Horizon	Depth, cm	Hygroscopic moist. %	Ignition loss %	SiO_2	R_2O_3	Fe_2O_3	Al_2O_3	CaO	MgO	Na_2O	K_2O	Total
89	A_0A_1	0—5	3,66	12,51	70,90	22,38	5,66	16,72	2,56	2,08	1,41	2,03	100,66
	A_1	9—14	3,42	10,21	69,67	21,33	5,19	16,14	2,42	2,11	1,60	2,07	99,20
	A_1A_2	20—25	2,62	5,22	72,12	20,48	4,87	15,61	1,94	2,20	1,57	1,88	99,69
	A_h	40—45	3,14	5,26	70,60	23,19	6,27	16,92	2,16	1,98	1,43	1,78	100,64
	»	65—70	4,02	5,14	69,42	24,82	6,85	17,97	2,51	3,04	1,18	1,59	102,06
	B_1B_2	95—100	4,41	4,61	66,89	25,32	7,02	18,30	2,27	2,34	1,38	1,84	99,54
	C	145—150	4,36	3,70	67,80	24,67	6,93	17,74	2,09	2,03	1,17	1,33	99,05

Note: Comma represents decimal point.

Table 3

Physical and chemical analyses of soil (calculated on absolute dry weight)

Profile No.	Horizon	Depth, cm	Hygroscopic moisture, %	pH		Humus, % (accord. to Tyurin)	Hydrolytic acidity (meq)	P_2O_5 Avail. (mg/100g)	K_2O Avail. (mg/100g)	Cation adsorption (meq) (according to Gedroyts)				Non-saturation by H (%)	% Ca of total	Fe (mg/100 g) (accord. to Kirsanov)
				Water	Salt			(accord. Kirsanov)	(accrd Peyve)	Ca	Mg	H	Sum of cations			
89	A_0A_1	0—5	—	5,9	5,5	8,4	9,8	6	20	29,9	7,7	0,7	38,3	2	78	7,89
	A_1	9—14	4,4	6,0	4,8	8,2	9,9	5	16	26,6	6,2	1,0	33,8	3	79	30,50
	A_1A_2	20—25	3,7	6,2	4,6	2,4	7,1	7	16	18,5	5,1	1,0	24,6	4	75	31,59
	»	27—32	3,6	6,2	4,7	2,3	6,7	10	16	20,7	4,3	0,8	25,8	3	80	31,89
	A_h	40—45	4,0	6,2	4,6	2,9	6,9	10	20	25,4	5,8	0,5	31,7	2	80	31,50
	»	65—70	5,3	6,3	4,8	1,5	5,2	10	20	31,1	7,1	0,1	38,3	0	80	29,88
	B_1B_2	95—100	5,6	6,3	4,8	0,8	3,7	2	20	33,1	7,1	0,05	40,3	0	82	25,31
	C	145—150	5,0	6,3	4,9	0,7	3,2	—	—	34,7	6,7	0,05	41,5	0	83	25,41
50	A_0A_1	0—2	11,1	6,5	5,8	66,7	9,1	Not det'd.		95,7	27,3	0,9	123,9	0,8	78	Нет
	A_1	2—7	4,2	5,5	4,5	5,1	4,8	"		19,4	2,5	0,9	22,8	3,9	85	20,88
	A_1A_2	12—17	4,0	5,3	4,1	2,9	5,6	"		16,5	3,7	1,8	22,0	8,2	75	31,23
	A_h	30—35	5,0	5,2	3,8	3,2	7,2	"		19,4	1,8	2,8	28,6	9,8	68	21,06
	B_1B_2	70—75	5,7	5,1	4,0	1,0	3,1	"		24,4	3,4	0,8	31,6	2,8	77	31,80
	C	130—140	5,3	6,7	5,3	0 5	1,2	"		28,2	3,4	0,2	31,8	0,6	89	31,71

Table 4

Group and fractional composition of humus[a] Profile 50

Depth, cm	Total C, %	% humus (C x 1.72)	% total C										Humic acid C Fulvic acid C	Total recovery	Available C (humic acids) as % of total C	Available C (humic acids) as % of C humic acids
			C content in benzalcohol extract of the wax resin	C decalcinated	Humic acid C				Fulvic acid C							
					Fractions				Fractions							
					I	II	III	C fraction total	I[b]	II	I+II	C soil residue				
2—7	3,8	6,5	5,3	5,3	19,1	2,5	4,2	25,8	20,5	1,6	22,1	33,4	1,2	92	19,1	74
12—17	1,7	2,9	5,2	8,1	24,1	6,2	2,3	32,6	23,8	1,7	25,5	25,6	1,3	97	24,1	74
30—35	1,9	3,2	2,1	3,7	21,5	30,1	1,6	53,2	19,0	0,5	19,5	20,0	2,7	98	21,5	40

[a] The analysis was performed by N. A. Pankovaya

[b] The fraction I fulvic acid corresponds to the sum of fractions I and II according to Tyurin

Note: Comma represents decimal point.

Ah is 2.7, which is considerably in excess of the ratio in the first two horizons and very near the ratio in steppe and meadow-steppe soils (Table 5).

The fractional composition of the humic group also reveals a sharp distinction between the humus content in the two upper horizons (A_1 and A_1A_2) and the Ah horizon. Humic acids in the upper horizon are represented mainly by mobile forms (ulmic acids), which can be extracted by treating 0.1 N NaOH directly without preliminary decalcification. The amount of mobile C humic acids in these horizons is 74% of the total amount of C in the humic group, while the amount of C in humic acids in fraction II is only 9.7% altogether in horizon A_1, and 19% in horizons A_1A_2 of the total amount in the C in humic group. Such a ratio between the C fractions in the I and II humic groups is characteristic of forest and forest-steppe soils. Of the humic acids in the second humus horizon, 50% are firmly consolidated forms connected mainly with calcium and recoverable with 0.1 N NaOH only after preliminary decalcification of the soil.

The data in Table 5 show that the humus content in the second humus horizon bears a similarity to the humus content of chernozem and meadow-chernozem soils, as well as to that of the second humus horizon described by Dolgovaya (7). We can therefore classify the second humus horizon with soils of the steppe (or meadow-steppe) series rather than with forest soils.

From the foregoing, it is clear that the distinct morphological character of the second humus horizon correlates with the sharp difference in the character (composition) of the humus in the upper horizons (A_1 and A_1A_2) and in the second humus horizon (A_h). Palaeogeographic data (18, 16, 12) indicate that in territories where soils with a second humus horizon occur, steppe associations have been replaced by forest associations in the distant past.

On the basis of our own morphological observations and analytical data, and considering the palaeogeographical indications that the territory under study was once steppe land, we believe that the second humus horizon in the grey forest soils of the Pirovo district in the Krasnoyarsk territory are a relict of meadow-chernozem or chernozem-meadow soils which were apparently once widespread in this area. In view of the fact that in different regions of the country, the morphology and chemical properties of the second humus horizon have their own distinctive characteristics (8, 15, 14), we assume that there are several ways in which this horizon can form, with the result that its nature can also vary.

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Table 5

Group and fractional composition of humus in certain soils

Soil	Horizon, cm	Humic acid fractions			Humic acid C	Fulvic acid C	Humic acid C / Fulvic acid C	Investigators
		I	II	III				
Degraded chernozem	—	12	25	7	44	20	2,2	I. V. Tyurin (19)
Meadow-chernozem	—	9	23	8	40	20	2,0	"
" "	0—10	4,8	27,4	4,8	37	24	1,5	I. V. Vishnevskaya (3)
	20—30	4,3	36,2	3,9	44,4	17,3	2,5	
Secondary podzolic	5—8	Not det'd.			28	20	1,4	I. V. Tyurin (19)
	25—35	"			42	17	2,5	
Leached chernozem	0—10	10	32	8	50	17	2,9	A. S. Dolgova (6)
Secondary podzolic	5—8	17	7	7	31	19	1,6	
	25—35	0	28	14	42	17	2,5	
Grey forest with A_h horizon. Pr.50	2—7	19,1	2,5	4,2	25,8	22,1	1,2	Ye. M. Naumov
	30—35	21,5	30,1	1,6	53,2	19,5	2,7	

Note: Comma represents decimal point.

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WATER-STABILITY OF THE STRUCTURE OF DIFFERENT SOIL GROUPS AND ITS DEPENDENCE ON AGRICULTURAL PRACTICES

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A great deal has been published both in our own and in foreign literature about direct and indirect methods of determining the water-stability of soil structure. Until now the method most widely used in our country is that of N. I. Savvinov (8). Its shortcomings have been pointed out in the literature (1, 2, 7).

In 1952, P. V. Vershinin presented the latest model of a special apparatus for studying objectively the water-stable structure and slaking of soils (3). This apparatus considerably widens the limits of investigation, and makes it possible to follow the dynamics of slaking of both structural and nonstructural elements (rate, stages). From data provided by this apparatus we can draw comparative curves showing the genetic characteristics of soils and the effect upon them of various agricultural practices (3, 9).

We shall give our results using Vershinin's apparatus.

We used samples of several types of soils amenable to rapid capillary wetting with water supplied from below in a fine stream, and slow capillary wetting with water supplied through filter paper. The two treatments gave completely different results, confirming well-known observations that, with slow capillary wetting of samples, soil aggregates acquire a much greater water-stability than they do with rapid immersion in water (4, 5, 6).

Comparing the analysis results of various soil samples (Table 1) we see that with rapid capillary wetting (and proportionately more with simultaneous rapid wetting) these soils take considerably longer sedimentation than they do with slow capillary wetting. This is because with rapid wetting a large amount of aggregates were dispersed by the air displaced by the water, and a large number of siltlike particles of <0.25 mm diameter were formed. This lengthened the elutriation time. Thus, a sod-podzolic fine clay loam siltlike soil from the Detskosel'skiy sovkhoz, Leningrad region, with rapid wetting, elutriates completely of water-unstable aggregates in 7-12 minutes and with slow capillary wetting in 2-6 min (Fig. 1); in the first case turbidity was great during the first minute (40-65 galvanometer units) and the total amount of water-stable aggregates smaller (21%-45.8%), whereas in the second case turbidity was considerably less (92-95 galvanometer units), and the total amount of water-stable aggregates larger (68%-77%. See Table 1 and Fig. 1). A similar type of elutriation in relation to wetting was observed in other types of soil (Figs. 2 and 3).

The results of these analyses show clearly the genetic characteristics of each soil group. Thus, while sod-podzolic fine clay loam silt-like soil, with rapid capillary moistening, elutriated completely of water-unstable aggregates in 7-12 minutes (Fig. 1), and leached fine clay loam silt-like Omsk chernozems and Stavropol' chernozems of similar texture elutriated in 9-10 minutes, an ordinary chernozem clay from the Kamennaya steppe took 7-11 minutes (Fig. 2). The first of these soils elutriated readily (with a sharp fall in turbidity) during the first 5-7 minutes and elutriation was gradually completed in the next 2-5 minutes, whereas chernozems elutriated steadily throughout, and their curves are convex and extended.

In sod-podzolic soils the cultivated layer slakes less readily, because it contains more organic matter and adsorbed calcium than the sub-cultivated layer, which has only negligible amounts of these substances. In horizon A_p (depth 0-10 and 10-20 cm) the turbidity during the first minute reached only 65-83 galvanometer units and the sum of water-stable aggregates was 45%, whereas in the podzolic horizon (20-30 cm) and particularly in the illuvial horizon (30-40 cm), the turbidity decreased to 50-40 units, and the total amount of water-stable aggregates to 28%-21%, or even to 12%-0%, as in fresh sample with undisturbed structure (Table 1).

In an ordinary chernozem from the Kamennay steppe, on the other hand, the cultivated layer occurring at 0-15 and 15-30 cm (turbidity up to 51 units, sum of water-stable aggregates >0.25 mm in diameter, 44%-47.4%) slaked more easily and the lower part of the humus horizon occurring at 30-45 cm (turbidity not more than 80 unit sum of water-stable aggregates 64.7%; Fig. 2), slaked less readily. This is because the structu of the cultivated layer of chernozems is less water-stable than that of the sub-cultivated layer of the humus horizon, which are not apt to be brought to the surface during plowing. A similar pattern is observed in Omsk chernozems (A_p, depth 0-30 cm, sum of water-stable aggregates 31.4%) and Stavropol' chernozems (A_p, depth 0-15 cm, sum of water-stable aggregates

Table 1

Percentage of water-stable aggregates in samples of various soils, determined by P. V. Vershinin's apparatus

Chernozem						Dark-chestnut from the Stavropol' Trans-Volga region, Yershov exp. area, cult.			Sod-podzolic, Leningrad oblast', mixed samples, cultivated				Sierozem	Takyr crust	Sod-podzolic Vologda Obl loess	Loess from Chwangho district (China)	Quaternary clay	Cambrian clay, schist
Ordinary, from Kamennaya steppe, cultivated			Leached, from Omsk oblast'		Ciscaucasian (Stavropol' subdistrict)								From Namangan				Leningrad	
			cultivated mix samp															
Depth, cm																	Depth, m	
0–15	15–30	30–45	0–30	0–20	0,15	0–10	10–22	25–35	0–10	10–20	20–30	30–40	0–10	0–3	0–10	180–229	10	25
Rapid capillary wetting; after saturation the samples were 1 hour in water																		
47,45	44,1	64.68	31,4	61,8	32,7	38,8	45,5	57,0	45,2	45,8	28,3	21,0	4,0	10,5	91,2	1,5	25,7	88,5
Slow capillary wetting on filter-paper; after saturation the samples were in water from 1 to 45 hours																		
83,0	78,1	86,2	62,9	84,2	65,9	85,7	86,7	77,2	68,1 84,1[a]	67,7 39,3[a]	76,5 12,13[a]	76,9 0[a]	18,5	26,7	—	20,3	37,6	98,6

[a] Samples with undisturbed structure and natural moisture, taken from the same area.

Note: Comma represents decimal point.

32.7%).

Dark-chestnut clay soil from the Yershov Experimental Area (Saratov region) was similar to chernozem as regards slaking, i.e., here, too, the steppe type of soil-formation appears clearly: the cultivated layer of the humus horizon (depth 0-10 and 10-22 cm) had a turbidity up to 52-62 galvanometer units and the sub-cultivated transitional layer (occurring at 25-35 cm) and carbonate layer (35-45 cm), almost devoid of humus and effervescing vigorously with HCl, showed up to 65-75 units and contained 33.6%-54% water-stable aggregates in the cultivated layer and 57%-70% in the sub-cultivated layer (Tables 1 and 2; Fig. 4).

Sierozem from Namangan (A_p, depth 0-10 cm; Fig. 3) was similar, as regards slaking, to the illuvial horizon of a sod-podzolic soil, but the intensity of slaking was considerably greater (turbidity in the first 30 seconds reached 13 galvanometer units, and only a negligible amount (4%; Table 1) of water-stable aggregates remained.

A lump of takyr crust from the same area was similar, as regards slaking, to sierozem (turbidity in the first minute 17 units), but the curve after the first minute was flatter and elutriation was not completed until 10.5 minutes, whereas with sierozem it took 7.5 minutes. Water-stable aggregates, of a flaky character were up to 10.5%.

Loess from depth 1.8-2.29 m, was similar to sierozem as regards slaking; the maximum turbidity in the first 30 seconds reached 15 galvanometer units but then decreased sharply, and slaking was almost completed during the fifth minute. Elutriation resulted in the complete disappearance of aggregates and the appearance, instead, of up to 1.5% fine calcareous tubes 0.5-1.0 mm in diameter and up to 5 mm long.

Finally, Cambrian clay (Fig. 3), after one hour's wetting, gave the following slaking pattern: greatest turbidity was observed during the first half-minute; the galvanometer needle did not fall below 87 units and, during the next 5 minutes, rose again to 95-99 units remaining there for 17 minutes until the end of the observations. After drying, the percentage of water-stable aggregates, leafy-schistous-flaky in shape, was 88.5.

With slow capillary wetting the pattern changed sharply. The cultivated layer of sod-podzolic Leningrad soil elutriated in 1.5-2 minutes; the initial turbidity did not fall below 92-95 galvanometer units, and the total amount of water-stable aggregates was not lower than 67.7%, as compared with the 45.2% obtained with rapid capillary wetting (Table 1 and Fig. 1).

The humus horizon of an ordinary chernozem from the Kamennaya steppe elutriated in 2.5-4 minutes; the initial turbidity did not fall below 91-83 galvanometer units, the sub-cultivated layer occurring at 30-45 cm hardly elutriated at all, and the turbidity increased by only two units. The total amount of water-stable aggregates was not lower than 78%-86%, as compared with the 44%-64.7% obtained with rapid capillary wetting.

Omsk leached chernozem cleared in 5-6

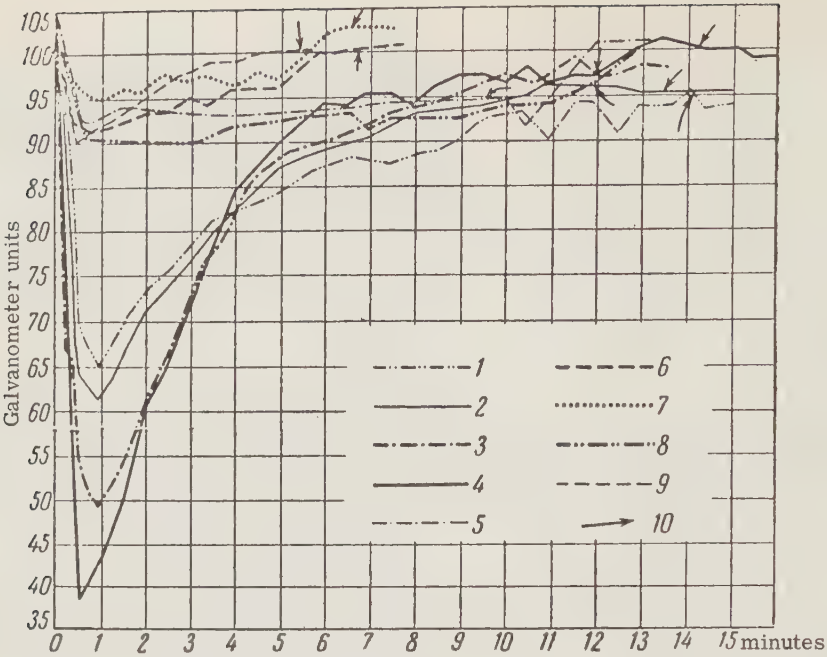

Fig. 1 - Dynamics of slaking of soil structure with rapid and slow capillary wetting by water

Depth of samples, cm: 1 - 0-10; 2 - 10-20; 3 - 20-30; 4 - 30-40, (rapid wetting); 5-0-10; 6 - 10-20; 7 - 20-30; 8 - 30-40, (slow wetting); 9 - sample of virgin soil from forest, sod-podzolic soil from Vologda Oblast' (rapid wetting); 10 - time of switching off the apparatus.

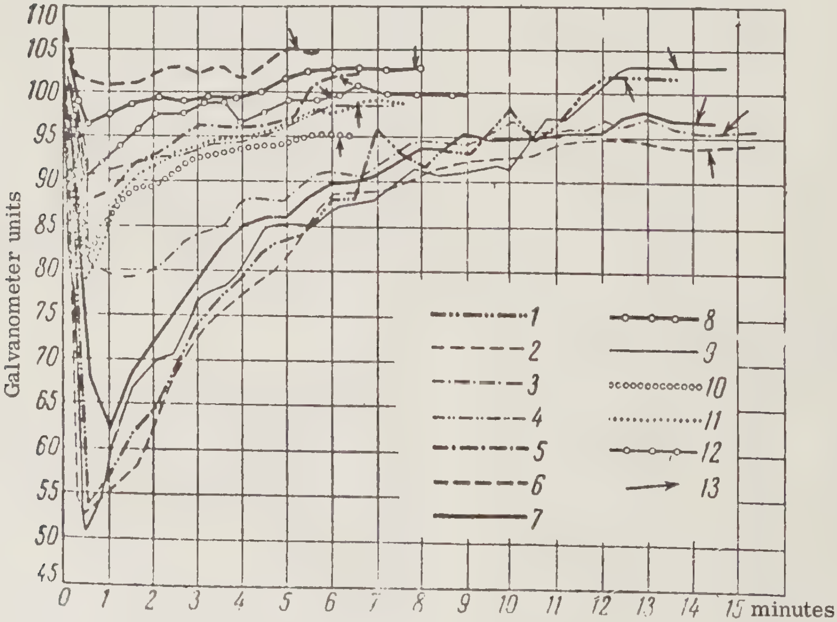

Fig. 2. - Dynamics of slaking of soil structure with rapid and slow capillary wetting by water

Ordinary clay chernozem from the Kamennaya steppe. Depth, cm: 1 - 0-15; 2 - 15-30; 3 - 30-45; (rapid wetting); 4 - 0-15; 5 - 15-30; 6 - 30-45 (slow wetting); Ciscaucasian chernozem, fine clay loam from the Stavropol' sub-district, depth 0-20 cm, wetting; 7 - rapid; 8 - slow. Leached chernozem from the Omsk Oblast', cultivated land, depth 0-30 cm, wetting; 9 - rapid; 10 - slow; the same soil, 11-year abandoned land, depth 0-20 cm, wetting; 11 - rapid; 12 - slow; 13 - time of switching off the apparatus.

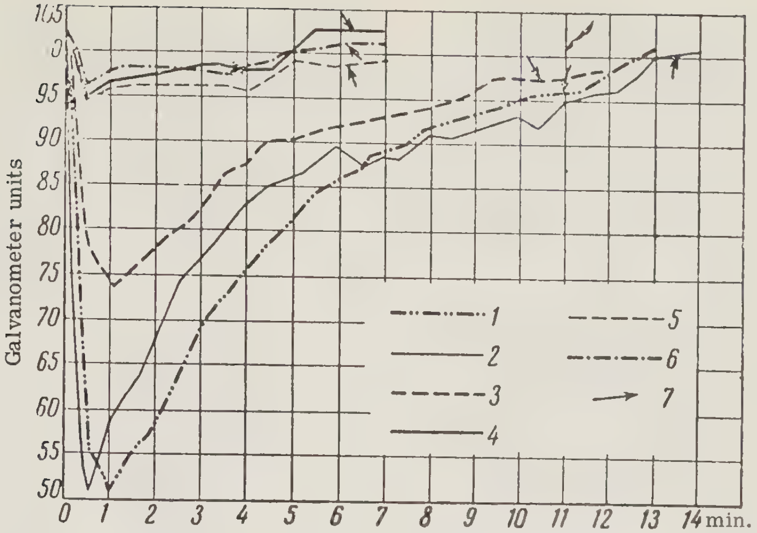

Fig. 4 - Dynamics of slaking of the structure of dark-chestnut clay soil with rapid and slow wetting by water

Depth, cm: 1 - 0-10; 2 - 12-22; 3 - 25-35 (rapid wetting); 4 - 0-10; 5 - 12-22; 6 - 25-35 (slow wetting); 7 - time of switching off the apparatus.

minutes; the turbidity during the first half-minute did not fall below 82 units; it reached 90 units in 1.5 minutes and elutriation was gradually completed in 5.5 minutes (Fig. 2). The total amount of water-stable aggregates was almost 63% as compared with the 31.4% obtained with rapid capillary wetting.

Similar curves were obtained for Ciscaucasian (Stavropol') chernozem, where elutriation was completed in 2 minutes, the turbidity not falling below 97 galvanometer units and the total amount of water-stable aggregates being almost 66% as compared with the 32.7% obtained with rapid capillary wetting (Table 1 and Fig. 2).

Elutriation of the humus horizon of dark-chestnut soil from the Yershov area (Saratov Trans-Volga region) was completed in 1.5 minutes; the initial turbidity of the water did not fall below 88-90 galvanometer units (Fig. 4) and the sum of water-stable aggregates was 85.7%-86.7% as compared with the 38.8%-45.5% obtained with rapid capillary wetting (Table 1 and Fig. 4).

Sierozem and takyr soils had similar curves. Slaking of these soil samples up to 95 galvanometer units required almost 23 minutes; the greatest turbidity (73 units) occurred 2 minutes after slaking (in other soils, 0.5 min) and then gradually decreased for 20 minutes, although complete slaking did not take place within this time as the curve rises. The total amount of aggregates left over from slaking with slow capillary wetting was 4.5 times greater in sierozem, and more than 2.5 times greater in takyr, than with rapid capillary wetting (Table 1).

Slaking of loess was completed in 3.5 minutes and the curve becomes horizontal at 96 galvanometer units. The greatest turbidity occurred during the first half-minute, and then the curve rose sharply for 3.5 minutes — until the completion of slaking. There remained 20% water-stable aggregates (with rapid wetting loess was completely slaked; Table 1 and Fig. 3).

Finally, Cambrian schistous strongly-compacted clay hardly slaked at all with slow capillary wetting. The curve of this process remained at zero (pure-water point), showing traces of slaking. After 16 minutes, 98.6% of the clay remained unslaked.

It is interesting to follow the effect of perennial grasses on the slaking of water-stable aggregates. Determinations were made on dark-chestnut clay soils from the fields of the Yershov Experimental Area (Saratov region). The results are summarized in Table 2.

With rapid capillary wetting the general pattern of slaking was similar for all samples, as they were of the same type, and from the third minute the curves run almost parallel. For the first 3 minutes, however, there are considerable differences in the course of the curves.

As would be expected, samples collected in a field under grasses for 3 years resisted slaking better (turbidity during the first minute was 66.5 galvanometer units and the total amount of water-stable aggregates up to 53.9%). Then come samples collected from under grasses of the second and first years of utilization (turbidity during the first minute 51-54 units, total amount of water-stable aggregates, 51%-52%). Next come samples from under wheat following grasses (turbidity during the first minute, 62 units, and total amount of water-stable aggregates, 44%; Fig. 4). Then come samples from under wheat undersown with grasses (initial turbidity 52 units, and water-stable aggregates, 41.6%). Last come samples from under potatoes planted in the third year after grasses (initial turbidity 36 units, water-stable aggregates, 33.6%).

In most samples the upper part of the cultivated layer (0-10 cm), covered by grasses, resisted slaking better than the lower (10-20 cm) horizon and contained more water-stable aggregates. Only under potatoes was the upper layer, having no grass cover, less resistant to slaking. It had a lower percentage of water-stable aggregates.

The sub-cultivated layer from all fields (depth 25-35 and 30-40 cm) slaked less readily than the cultivated layer (initial turbidity 65-77 galvanometer units and percentage of water-stable aggregates considerably higher — 58%-70%). Aggregates of 0.5-2 mm in diameter (the most effective) predominated in this layer, whereas in the cultivated layer aggregates of 0.25-1 mm in diameter predominated and the percentage of water-stable aggregates was 1-1/2 times lower than in the sub-cultivated layer.

Slow capillary wetting of dark-chestnut soils from under the same crops showed a completely different pattern of slaking. The elutriation of soils cropped to grasses, for example, was completed in 1.5-2 minutes. With samples in first year grass the initial turbidity did not fall below 93.5 galvanometer units and from second year grass, below 95 units. The total amount of water-stable aggregates with first year grasses did not fall below 85%-90% and with second year grass, 86.5%, as compared with 41%-50% and 52%-55% with rapid capillary wetting (Fig. 4). Elutriation of soil samples from third year grass was also completed in the first 2-3 minutes, the initial turbidity not falling below 87 units and the total amount of water-stable aggregates not being lower than 77.2%-86.7%, as compared with 50%-58% with rapid wetting.

Soil samples from under spring wheat following grasses elutriated in 5.5-6 minutes (initial turbidity not less than 83.5 units, total amount of water-stable aggregates 67%-80% as compared with 37%-62% in samples wetted rapidly). Soil samples from under spring wheat undersown with grasses elutriated in 5-6 minutes (initial turbidity not less than 82-88 units, water-stable aggregates 80%-87.6% as compared with 34%-70% with rapid wetting).

Finally, soil samples from under potatoes elutriated in 2-3 minutes (initial turbidity not greater than 85-93 galvanometer units, water-stable aggregates 74%-91% as compared with 33%-62% with rapid wetting).

Soils from old-abandoned and virgin lands had a markedly different slaking pattern. A sample of Omsk leached chernozem from an 11-year abandoned land (depth 0-20 cm) elutriated completely in 3.5 minutes with rapid capillary wetting; the turbidity did not fall below 78 galvanometer units during the first half-minute and rose to 92 units in the first 2 minutes. The total amount of water-stable aggregates was almost 62%, and with slow capillary wetting it was as much as 84% (Table 1 and Fig. 2). Sod-podzolic virgin soil from the Tot'ma district,

Table 2

Percentage of water-stable aggregates in dark-chestnut soil of the Saratov Trans-Volga region, determined by Vershinin's apparatus

Perennial grasses of various years of utilization									Spring wheat						Potatoes (3rd crop after grass), profile 8		
First year, profile 3			2nd year, profile 6			3rd year, profile 5			After grasses, prof. 12			Undersown with grass Profile 10					
0-10	12—22	30—40	0—10	12—22	25—35	0—10	12—25	25—35	0—10	12—22	25—35	0—10	12-22	25—35	0—10	10—20	30—40
Rapid capillary wetting; after saturation the samples were 1 hour in water																	
51,3	41,7	60,9	52,1	55,3	67,4	53,9	49,9	58,4	44,1	37,0	62,6	41,6	33,7	70,1	33,6	42,2	61,8
Slow capillary wetting, on filter-paper, hours																	
44			45			2,5			15			48			42		
85,2	90,4	86,9	86,6	86,5	89,3	85,7	86,7	77,2	67,0	71,5	79,9	80,5	82,4	87,6	74,25	91,5	84,5

Note: Comma represents the decimal point.

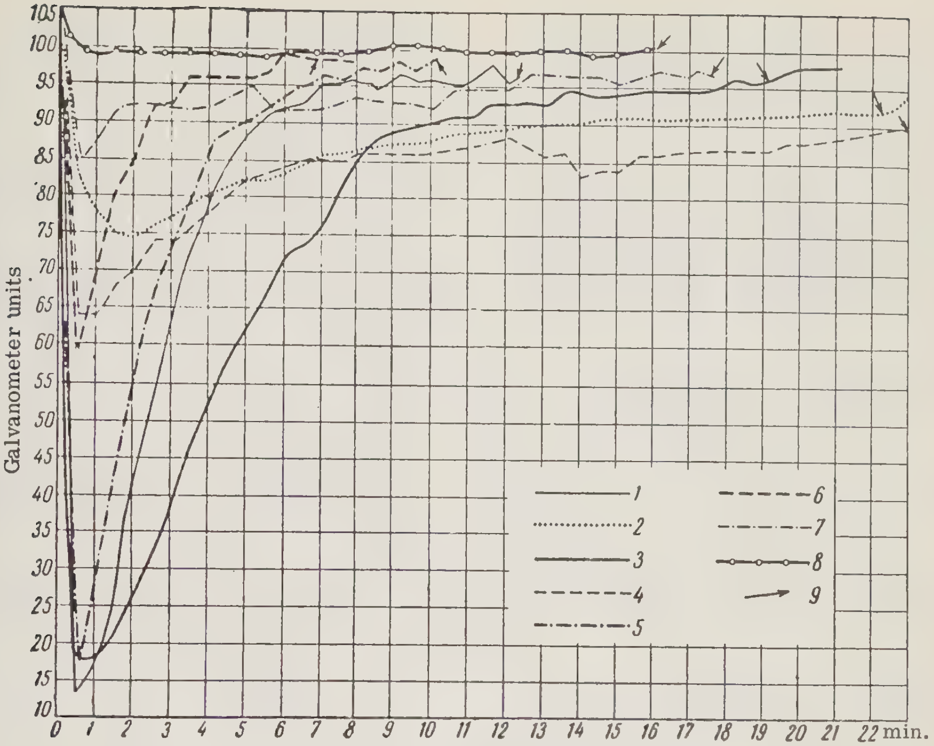

Fig. 3 - Dynamics of slaking of soil structure with rapid and slow capillary wetting by water.

Sierozem from Namangan, depth 0-20 cm, wetting: 1 - rapid; 2 - slow; takyr crust 3 cm thick, wetting: 3 - rapid; 4 - slow; loess, depth 180-230 cm, wetting: 5 - rapid; 6 - slow; Cambrian clay from Leningrad, depth 25 m, wetting: 7 - rapid; 8 - slow; 9 - time of switching off the apparatus.

Vologda region, elutriated completely in 4 minutes; in the first half-minute turbidity did not fall below 90 units and after 2 minutes was already 95 units. The total amount of water-stable aggregates was 91.2% (Table 1 and Fig. 1).

Conclusions

1. The more water-stable the structure (the greater the sum of water-stable aggregates of the fraction >0.25 mm in diameter), the more rapidly elutriation is completed (with both methods of wetting). Thus, in sod-podzolic soils the humus horizon elutriates more rapidly than does the podzolic horizon; in chernozems and dark-chestnut soils the lower layers of the humus horizon, having better structure, elutriate more rapidly.

2. With slow capillary wetting the time needed for elutriation decreases sharply, as the water-stability of the structure increases considerably. With soils of good structure, rich in humus, as a result of the mechanical destruction of aggregates (soils under grasses), clearing often did not occur at all, or it was negligible.

3. Ordinary chernozem from the Kamennaya steppe, having a large amount of organic matter and adsorbed calcium and a clay texture, has the most water-stable and least readily slaked structure. Leached Omsk chernozem has considerably lower water-stability of aggregates with any method of wetting. Ciscaucasian (Stavropol') chernozem has a somewhat greater water-stability than Omsk chernozem. Dark-chestnut soils of the Saratov Trans-Volga region, whose slaking pattern is typical of steppe soils, have somewhat lower water-stability than ordinary chernozems, but considerably higher than Omsk leached chernozem.

4. The lower (sub-cultivated) layers of the humus horizon of the steppe type of soil-formation (chernozems, dark-chestnut soils) differ from the cultivated layer in that they have considerably greater water-stability, especially with slow capillary wetting. The carbonate horizon of steppe soils also has high water-stability.

5. Sod-podzolic soils are markedly different from steppe types in their slaking pattern. When dry samples are wetted rapidly, only the humus horizon is water-stable; the remainder gradually slake completely. With slow capillary wetting the water-stability of all horizons increases

greatly and the elutriation time of water-stable aggregates decreases sharply. Fresh, undried, natural samples with undisturbed structure are water-stable only when taken from the humus horizon; the lower-lying A_2 and B horizons slaked completely.

With rapid wetting, sierozem soils from desert steppes are characterized by an almost complete absence of water-stable structure and by complete and steady slaking; with slow capillary wetting, about 18% aggregates remained. Hence the necessity of a slow capillary supply of water when irrigating sierozem soils.

6. Soils under grasses, virgin soils and old-abandoned land have a more water-stable structure than soils from bare fallow, from potatoes or from spring grain-crops.

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PROCEDURE FOR DETERMINING THE TOTAL CONTENTS OF MICROELEMENTS IN SOILS AND PLANTS

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Plant ashing, the combining of soils with the carbonates of alkali metals, and solution in mineral acids are widely used to determine he total soil content of various elements. These operations are time-consuming and reuire optical equipment, platinum vessels, electric and gas heaters, etc. Thus, although determination of the total content of microelements in plants and soils is of scientific and practical interest, it is quite complicated.

The aim of the present study was to develop:) a rapid method for the combustion of organic matter without the use of muffle furnaces; 2) a rapid method for obtaining soil solutions without using platinum vessel; 3) a method for determining the total contents of microelements Cu, Zn, Mn, Mo, B and Co) in which optical apparatus was replaced by scales of the mineral salt solutions or by celluloid scales.

Ashing of Organic Matter

The organic matter in a sample must usually be destroyed (i. e., oxidized to mineral compounds) to determine its mineral composition. The wet and dry ashing methods used (7) are very time-consuming. The author was developed he following more rapid method:

Air-dry plant samples are ground. The tems, straw and leaves are cut into 2-4 mm ragments and large seeds are ground in such a way as to yield as few dust particles as possile. A ground sample of known weight is aken (Table 1).

The first five microelements listed are determined from the general sample, but a separate sample is taken for boron. The sample is laced in a porcelain dish or crucible (50 ml), eated over a strong electric plate, and caronized. When smoke appears the sample hould be ignited. It is known that flame comustion does not entail any loss of the mineral art of the ignited material. The porcelain ish and sample are covered by another porelain dish to twice the capacity (100 ml). The ish with the sample is heated on the strong lectric plate and HNO_3 fumes are introduced hrough opening in the upper dish. The fumes are roduced by the heating of concentrated H_2SO_4 nd 95% HNO_3 (1:1) in a flask. The HNO_3 with specific gravity of 1.4 can also be used if the $H_2SO_4 - HNO_3$ ratio is 2:1. Fine capillaries, approximately 0.5 mm in diameter and 1-1.5 cm long, one end sealed into a small (1-3 mm) globe, are used to ensure even liberation of the fumes in the flask. From time to time these capillaries should be washed in hot water and dried. Figure 1 shows a general view of the ignition apparatus. All parts of the apparatus are attached to the stand by movable ring clamps.

During ignition the passing of HNO_3 fumes should be interrupted every 10-20 seconds by removing the heater from the flask. The oxidized material should be examined by raising the holder of the flask and outlet tube on the stand and lifting the upper dish.

Oxidation is complete when the residual ash is light in color and free from black carbon particles. A 5 g sample can be ignited in 2-5 minutes. The H_2SO_4 can be recovered by evaporating until SO_3 fumes emerge.

When determining Cu, Zn, Mn, Co and Mo in a single sample, the ash, after cooling, is moistened with concentrated HCl and evaporated until dry, remoistened with concentrated HCl, washed with hot distilled water acidified with HCl (1:100), and filtered through an ash-free filter into a 100 ml volumetric flask. The filtrate is used in the required amounts to determine separate microelements (Table 1).

When determining boron, the sample is ashed in the same manner. Note that the reaction (pH) of the ash remains alkaline and there is no loss of boron. After cooling, the ash is moistened once or twice with 4-5 drops of concentrated HCl and evaporated to dryness very slowly at a temperature not exceeding 80°C (a well-covered water bath can be used).

Obtaining Solution for Determining the Total Microelement Content of Soils. The usual method for the determination of various elements in soils is to combine a soil sample with soda or potash, or a mixture of the two, or to decompose the soil with various mineral acids (1, 2, 3, 5).

The following method of decomposing soil samples has been evolved to permit the replacement of the platinum vessel by a glass one and to use readily available reagents. Air-

Table 1

Approximate weights of plant samples and total analytical volume of filtrate

Microelement	Determination of microelements					
	Each separately			In a single sample		
	Sample, g	Total volume of filtrate	Volume of filtrate for analysis	Sample, g	Total volume of filtrate	Volume of filtrate for analysis
		In milliliters			In milliliters	
Cu	1,0	10	2,5—7,5	10	100	2,5—7,5
Zn	1,0	10	0,5—1,0			0,5—1,0
Mn	1,0	10	5—10			5—10
Co	5—15	25	25			50
Mo	5	25	10—20			30
B	0,25—1,0	10	1—5	None	None	None

Note: Comma represents decimal point.

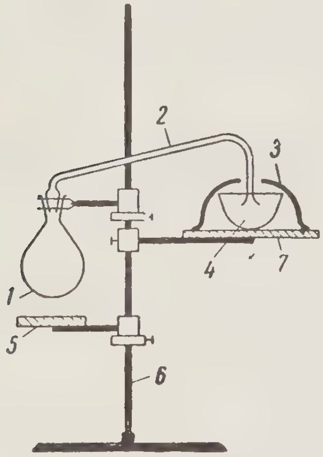

Fig. 1. - General view of the ashing apparatus.

1 - flask with ground stopper; 2 - tube to conduct fumes; 3 - cover dish; 4 - dish with sample; 5 - 7 - electronic heaters; 6 - stand.

dry samples of the soils are pulverized in a mortar (preferably agate) and samples of known weight are taken (Table 2).

A sample containing very little organic matter is placed in a 100 ml wide-necked conical flask of heat-resistant glass and dried at a gentle heat until there are no drops of water on the walls of the flask. The heat is then increased and the organic matter oxidized with HNO_3 fumes. The end of the delivery tube through which the HNO_3 fumes pass should be 1.0-1.5 cm above the soil layer. If there is a great deal of organic matter in the sample it should be oxidized in a porcelain dish or crucible, as in the ashing process. Soil organic matter is ashed very rapidly and the sample becomes lighter in color. Concentrated HNO_3 (not more than 2 ml per g of soil) is used to transfer the residue to a flask for further treatment with acids. The same amount of HNO_3 is added to samples ashed in flasks. After cooling, concentrated H_2SO_4 is added in the proportion of 0.8 ml to 1 g of soil for clay soils, 0.6 ml for clay loams, 0.5 ml for sandy loams and 0.4 ml for sandy soils.

The contents of the flask are heated gently until SO_3 fumes are evolved and then evaporated at increased heat until dry. We recommend tha the flask be surrounded by a conical asbestos jacket (Fig. 2). The flask is then cooled and concentrated H_2SO_4 is added in the proportion of 0.4 ml per g for clay soils, 0.3 ml for clay loams, 0.2 ml for sandy loams and 0.2 ml for sandy soils, in addition to 1 ml each of concentrated HCl and 30% H_2O_2. As before, the contents of the flask are evaporated until dry. Concentrated HCl is added in the proportion of 0.5-0.7 ml per g, the mixture is boiled, 3-5 ml of acidified water are added and the mixture is again boiled for a few seconds, then filtered. The flask and filter are washed 3-4 times with boiling acidified (1:100) water. The filtrate is ready for direct determination of the microelements when the solution has been brought up to the scale marks in a volumetric flask.

The following method has been worked out for obtaining the soil solution for analysis to determine total boron content:

Air-dry soil is passed through a 0.25 mm mesh sieve and the organic matter is removed (0.6-1.0 g for sandy soils and 0.3-0.5 g for clay soils) by oxidation with HNO_3 fumes, as in ashing. The residue is passed from the porcelain dish through a heated funnel into the flask of the heating device (Fig. 3).

The dish and funnel are washed with concentrated H_2SO_4, and 5 ml are added to the flask. The flask is then connected to the condenser of the heating device (the flask and condenser are of LKP glass) and boiled for 3

Table 2

Approximate sample weights of total soil and volume of analyzed filtrate

Micro-element	Determination of microelements					
	Each separately			All in one sample		
	Sample, g	Total volume of filtrate	Volume of filtrate for analysis	Sample,g	Total volume of filtrate	Volume of filtrate for analysis
		In milliliters			In milliliters	
Cu	1	50	2,5—7,5	3,0	100	5
Zn	1	50	0,5—1,0			0,5—2,0
Mn	1	50	5—10			5—10
Co	2	50	50			50
Mo	1,5	50	30			30

Note: Comma represents decimal point.

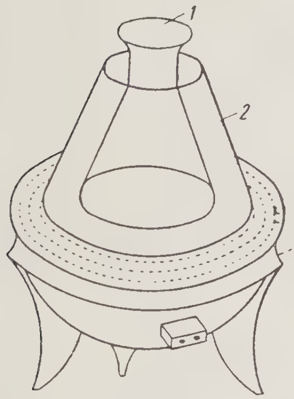

Fig. 2. - Apparatus for ashing the soil sample.

1 - flask; 2 - asbestos jacket; 3 - electric plate.

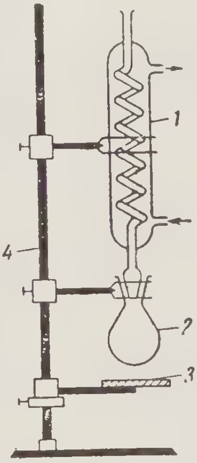

Fig. 3. - Diagram of the heating device.

1 - condenser with coil; 2 - flask; 3 - electric heater; 4 - stand.

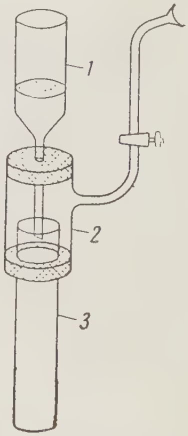

Fig. 4. - Filter device.

1 - Nutsch No. 4 filter; 2 - vacuum tube; 3 - test tube for filtrate.

minutes. Heating is discontinued and the contents of the flask are cooled and 0.5 ml of 30% H_2O_2 are added. Heating is then continued until SO_3 fumes reach the condenser coil. After cooling, the flask is disconnected but not removed from the condenser. The condenser coil is washed out with 3.0 followed by 2.5 ml of concentrated H_2SO_4, which collect in the same flask. The contents of the flask are violently shaken and poured in one operation onto a No. 4 glass filter in the filtering device (Fig. 4). The filter and test tube should be dry. The filtrate obtained from filtration in a vacuum is used to determine boron.

Colorimetric Scales for the Solutions Analyzed. It is best to use a series of graduated standards to determine microelements by colorimetric analysis. A recommended scale of standard solutions and the procedure for its preparation are described by Peyve and Rin'kis (4). Since the scales of the standard solutions are unstable and their color changes rapidly, they should be prepared at the time of analysis. This is very time-consuming. A procedure has therefore been developed to produce substitute scales of standard solutions — colored celluloid scales and scales of solutions of mineral acids, which can be used for a long time to compare the analyses. Preparation of the colored celluloid scales is described by Peyve and Rin'kis (4). Since scales of mineral acid solutions are easier to prepare, we indicate the method below.

Solutions required:

1) 20 g $CuSO_4$ x $5H_2O$ are dissolved, and distilled water added to 100 ml;

2) 9.5 g $CoSO_4$ x $7H_2O$ are dissolved, and distilled water added to 100 ml;

3) 0.1 g $K_2Cr_2O_7$ as above;

4) 3.8 g $CoSO_4$ x $7H_2O$ as above;

5) 200 g HPO_3 are dissolved in 120 ml of distilled water during heating and the solution is stirred frequently. The solution is subsequently boiled for 3 minutes, cooled and brought up to 145 ml with distilled water;

6) 1.0 g $CoSO_4$ x $7H_2O$ and 0.3 g $CuSO_4$ x $5H_2O$ are dissolved in 15 ml of distilled water, 70 ml of solution 5 are added, the solution is boiled for 3 minutes and brought up to 70 ml with distilled water after cooling;

7) 7.0 g $CuSO_4$ x $5H_2O$ are dissolved in 15 ml of distilled water, 75 ml of solution 5 are added, the solution is boiled for 3 minutes and brought up to 75 ml with distilled water after cooling;

8) 3.0 g $CoSO_4$ x $7H_2O$ are dissolved in 15 ml of distilled water, 75 ml of solution 5 are added, the solution is boiled for 3 minutes and brought up to 75 ml with distilled water after cooling;

9) 6.5 ml of solution 2 and 100 ml of distilled water are added to 10 ml of solution 3.

To prepare scales for the determination of the separate microelements, these solutions are mixed in calibrated test tubes (Table 3).

Owing to variations in the quality of the salts and reagents purchased, it is desirable that the prepared scales of mineral salt solutions be checked and corrected against standard solution scales.

Procedure for Determining the Microelements Cu, Zn, Mn, Co, Mo and B in Soils and Plants

Copper. The required amount of filtrate (Tables 1 and 2) is placed in a test tube with a ground-glass stopper and 2-4 ml of a 25% solution of sodium citrate are added (if the citrate is not adequate, trivalent Fe oxidizes diphenylthiocarbasol to yield a yellow color) and the pH is brought to 1.5-2 on universal indicator paper. The Cu is next extracted by diphenylthiocarbasol in CCl_4 (2, 3, 8). Initially, 1 ml of diphenylthiocarbasol is used and, after vigorous shaking for 1/2 minute, the color is compared with the graduations of the color scale. If the extract is more red than the last division on the scale and the volume of the diphenylthiocarbasol solution is increased to 2.5 ml; 5.0 ml and 7.5 ml, repeating the procedure of shaking and color comparison each time. If the color of the extract is still more red than the last division on the scale at 7.5 ml, less of the filtrate is taken for the analysis. On the other hand, when the color is more green than the first division on the scale for 1 ml of diphenylthiocarbasol, a greater volume of filtrate should be taken. The completeness of extraction is tested by shaking and by comparison with the scale until the color remains constant.

Reagents

1. Diphenylthiocarbasol solution — approximately 0.01 g is dissolved in 50 ml of CCl_4 and filtered. A 50 ml amount of NH_4OH (1:20) is added to the solution in a separating funnel (200 ml), and shaken. The lower CCl_4 layer is drawn off and the water layer is washed 2-3 times with pure CCl_4, which is drawn off after each shaking.

Next 50 ml of CCl_4 is added and then approximately 25 ml of 1 N HCl, until the solution becomes green. On shaking, the diphenylthiocarbasol is inversely extracted in the CCl_4 layer.

The required concentration of diphenylthiocarbasol is obtained by adding the purified solution drop by drop to pure CCl_4 until the color of the solution is exactly the same as that of the zero mark on the scale. The diphenylthiocarbasol concentration should be approximately 0.001%.

2. NH_4OH 1:20 — one part of 25% NH_4OH is mixed with 20 parts distilled water;

3. HCl 1 N — 82 ml of concentrated HCl (specific gravity 1.19) is brought up to 1 liter with distilled water;

4. Sodium citrate 25% — 25 g of sodium citrate is dissolved and brought up to 100 ml with distilled water;

5. CCl_4;

6. Diphenylthiocarbasol.

Zinc. The required portion of the extract (Tables 1 and 2) is placed in a test tube with a ground-glass stopper and brought up to 5 ml with pure distilled water. Very acid solutions must be neutralized with 20% sodium acetate to pH 2.0 before adding the complex buffer solution. Next 2-4 ml of the complex buffer solution are quickly added to the solution in the test tube, and it is shaken rapidly. This is essential since the thiosulfate which is added as a complex-former is destroyed in an acid medium (it loses the capacity to form complexes and hinders the extraction of Zn by turbidity formation).

After adding the complex buffer, test with universal indicator paper to see that the pH is 5.5-6. If necessary, the pH is adjusted in the normal manner. Finally, the Zn is extracted by diphenylthiocarbasol in CCl_4 (2, 3, 8), as in the extraction of Cu.

Reagents

1. Diphenylthiocarbasol solution, prepared as described in the determination of Cu;

2. Complex buffer solution — 40 g sodium acetate + 40 g sodium thiosulphate ($Na_2S_2O_3$ x $5H_2O$) are dissolved in 200 ml of distilled water and purified with diphenylthiocarbasol;

Table 3

Quantity of solutions for preparation of scales in milliliters

Scale gradation	Cu					Zn					Mn			Co				Mo			B			
	Solutions			Distilled water	Cu (µg) in 1 ml of the solu. for colorimetry	Solutions			Distilled water	Zn(µg) in 1 ml of the solu. for colorimetry	Solutions		Mn(µg) in 1 ml of the sol. for colorimetry	Solutions		Distilled water	Co(µg) in 1 ml of the solu. for colorimetry	Solution	Distilled water	Mo (µg) in 1 ml of the sol. for colorimetry	Solutions			B (µg) in 1 ml of the sol. for colorimetry
	1	2	3			1	2	3			6	5		3	4			9			7	8	5	
0	7,0	0,7	2,0	0,3	0,0	7,0	0,7	2,0	0,3	0,0	—	—	—	—	—	—	—	—	—	—	1,3	2,8	4,0	0,0
1	6,2	1,2	1,7	0,9	0,1	6,3	1,3	1,6	0,8	0,05	0,5	9,5	0,5	1,10	0,0	8,90	0,05	1,0	5,0	0,2	1,5	2,7	4,0	0,05
2	5,4	1,7	1,4	1,5	0,2	5,6	1,9	1,2	1,3	0,10	1,0	9,0	1,0	1,15	0,2	8,65	0,1	2,0	4,0	0,4	1,7	2,6	4,0	0,10
3	4.6	2,2	1,1	2,1	0,3	4,9	2,5	0,8	1,8	0,15	2,0	8,0	2,0	1,30	0,6	8,10	0,2	3,0	3,0	0,6	1,9	2,5	4,0	0,15
4	3.8	2.7	0.8	2,7	0,4	4,2	3,1	0,4	2,3	0,20	3,0	7,0	3,0	1,45	1,0	7,55	0,3	4,0	2,0	0,8	2,1	2,4	4,0	0,20
5	3,0	3,2	0,5	3,3	0,5	3,5	3,7	0,2	2,6	0,25	4,0	6,0	4,0	1,60	1,4	7,00	0,4	5,0	1,0	1,0	2,3	2,3	4,0	0,25
6	2.2	3,7	0,2	3,9	0,6	2,8	4,3	0,0	2,9	0,30	5,0	5,0	5,0	1,75	1,8	6,45	0,5	6,0	0,0	1,2	2,5	2,2	4,0	0,30
7	—	—	—	—	—	—	—	—	—	—	6,0	4,0	6,0	1,90	2,2	5,90	0,6	—	—	—	2,7	2,1	4,0	0,35
8	—	—	—	—	—	—	—	—	—	—	7,0	3,0	7,0	2,05	2,6	5,35	0,7	—	—	—	2,9	2,0	4,0	0,40
9	—	—	—	—	—	—	—	—	—	—	8,0	2,0	8,0	2,20	3,0	4,80	0,8	—	—	—	—	—	—	—
10	—	—	—	—	—	—	—	—	—	—	9,0	1,0	9,0	2,35	3,4	4,25	0,9	—	—	—	—	—	—	—

Note: Comma represents decimal point.

3. Sodium acetate 20% — 20 g of sodium acetate are dissolved in 100 ml of distilled water and purified with diphenylthiocarbasol;

4. CCl_4;

5. Diphenylthiocarbasol.

The prepared saline solutions and distilled water are purified by shaking in a separatory funnel with a solution of diphenylthiocarbasol, drawing off the CCl_4 layer on each occasion until the green color of the diphenylthiocarbasol solution will no longer change. The vessel used is also washed carefully and rinsed in distilled water.

Manganese. To determine manganese alone in a separate sample the plant ash and soil must be dissolved in HNO_3 after evaporation of the H_2SO_4. The required amount of the solution (Tables 1 and 2) is placed in a 50 ml wide-necked flask of heat-resistant glass. The filtrates are evaporated with HCl until dry, 0.5-1.0 ml (in relation to the quantity of salts in the extract) of concentrated HNO_3 is added twice and evaporated until dry each time. The residue is dissolved in 0.3 ml of concentrated HNO_3 and 6 ml of the distilled water. It is not necessary to evaporate when determining Mn in a solution of HNO_3 containing no more than 0.5 ml of concentrated HNO_3.

Next is added 0.5 ml of concentrated H_2SO_4, 0.5 ml of 85% H_3PO_4 and 0.5 ml of 2% $AgNO_3$. This is boiled, and a little dry $K_2S_2O_8$ (not more than 0.6-0.9 g in all) is dropped in two or three times. When the solution becomes a stable red, it is diluted with distilled water to 10 or 20 ml or more until the coloration of the solution transfered to a test tube corresponds to one of the divisions on the Mn scale.

Reagents

1. Concentrated H_2SO_4, sp. gr. 1.84;

2. Concentrated HNO_3;

3. 85% H_3PO_4 — 85 g of H_3PO_4 are dissolved in distilled water and brought up to 100 ml;

4. 2% $AgNO_3$ — 2 g $AgNO_3$ are dissolved in distilled water and brought up to 100 ml;

5. Dry $K_2S_2O_8$ or $(NH_4)_2S_2O_8$.

Cobalt. In plants and soils with a low content of iron and other salts (sandy soils) the first method described below should be used; the second method being reserved for soils with a high level of salts (clay soils).

First method. If Co alone is being determined in plants or soils, it is best to dissolve the plant ash and soil in HNO_3 after evaporation of the H_2SO_4. The required amount of the solution (Tables 1 and 2) is placed in a 50-100 ml wide-necked flask of heat-resistant glass and evaporated until dry. If a solution with HCl is being analyzed, the residue after evaporation is wetted with concentrated HNO_3 and re-evaporated. The residue left after heating is dissolved in 3-6 drops of concentrated HNO_3 and 6 ml of distilled water. If the residue is not fully dissolved one drop of 30% H_2O_2 is added and the solution is boiled thoroughly. One or more drops of 1 N $KMnO_4$ are added to the hot solution (until it turns a rose color), and appro mately 0.3 g of dry sodium citrate. The soluti is heated, 0.3-0.5 g of dry sodium acetate is added and boiled. The pH of the solution (universal indicator paper) should be above 5.5 and can be increased, if necessary, by the addi tion of sodium acetate. Next is added 0.5, 1.0 ml or more (in relation to the color depth o the red Co complex formed) of 0.1 nitroso — R — salt. This is boiled for 10-20 seconds. A 3 ml amount of a mixture of H_3PO_4 and HNO_3 is added to the solution and it is brought up with distilled water to 10 or 20 ml or more, so that there are 0.5 ml of 0.1 nitroso — R — salt to 10 ml of the solution. The solution in the test tube is then compared with the Co scale.

Second method. To determine Co in soils with a large content of Fe or other salts and also when fused with carbonates it must be preliminarily extracted with a solution of diphenylthiocarbasol in CCl_4 (3). The required amount of the solution (Table 2) is placed in a 100 ml separatory funnel, one drop of phenolphthalein and 5-10 ml of 25% sodium citrate are added an it is neutralized with NH_4OH (1:1) until the color is light rose. Next, 5 ml of an approximately 0.05% solution of diphenylthiocarbasol are added, the mixture is shaken and the CCl_4 layer drawn off in a 50 ml wide-necked flask of heat-resistant glass. Extraction is repeated until the addition of a new quantity of the diphenylthiocarbasol solution fails to affect its green color. On the final extraction 3.5 ml of pure CCl_4 may be added in place of the diphenylthiocarbasol solution.

To the flask containing the collected extract 1 ml of concentrated HNO_3, 0.5 ml of concentrated H_2SO_4 and 1 ml of 30% H_2O_2 are added and the mixture is heated slowly at first, and then on a strong electric plate, and evaporated to dryness. If the residue is not white when SO_3 fumes are evolved, 1 ml of 30% H_2O_2 is added several times, without waiting for complete evaporation. The white residue is dissolved by the addition of one drop of concentrated HNO_3 and 3-5 ml of distilled water. Next approximately 0.2 g of dry sodium citrate, 0.3 of dry sodium acetate and 0.5, 1 ml or more of 0.1% nitroso — R — salt are added to the solution and boiled for 10-20 seconds. The resulting color of the solution in the test tube is compared with the scale for cobalt.

Reagents

1. Concentrated HNO_3;

2. H_2O_2 30%;

3. $KMnO_4$ 1 N — 31.6 g of $KMnO_4$ are dissolved and brought up to 1 liter with distilled water;

4. Dry sodium citrate;

5. Dry sodium acetate;

6. 0.1% nitroso — R — salt — 0.1 g of nitros

-R — salt are dissolved in 100 ml of distilled water;

7. Mixture of H_3PO_4 and HNO_3 — 5 parts of 85% H_3PO_4 are mixed with one part of concentrated HNO_3;

8. 1% phenolphthalein — 1 g of phenolphthalein is dissolved in 100 ml of ethyl alcohol;

9. 25% sodium nitrate — 25 g of sodium nitrate are dissolved and brought up to 100 ml with distilled water;

10. NH_4OH 1:1 — 100 ml of 25% NH_4OH are diluted with 100 ml of distilled water;

11. 0.05% diphenylthiocarbasol solution — 50 mg of diphenylthiocarbasol are dissolved in 100 ml of CCl_4 and filtered;

12. Concentrated H_2SO_4.

Molybdenum. The required amount of a solution of plant ash (if the volume is not more than 7 ml and does not contain more than 1 ml of concentrated HCl) is placed in a test tube, with a ground-glass stopper, in which the rest of the analysis is carried out. If the volume of the solution is greater, proceed as in the soil analysis or evaporate until dry in wide-necked heat-resistant flask, dissolve the dry residue in 1.0 ml of concentrated HCl + 5.0 ml of distilled water and transfer to the test tube.

The required amount of soil solution is placed in a 50-100 ml separatory funnel. The HCl is added, as required, to arrive at 1 ml of concentrated HCl to each 10 ml of solution. Both in the test tube and in the funnel 1 ml of 10% KCNS is added for each 10 ml of volume, the mixture is shaken, 1-1.5 ml of 10% $SnCl_2$ is added and the mixture is again shaken until the red color from ferric thiocyanate disappears. If there is very little iron in the solution, 1-2 drops of $FeCl_3$ must be added before addition of the $SnCl_2$. Next 1 ml of a solution of metaphosphoric acid is added to each 10 ml and shaken. Then 1.2, 2.2 ml or more of isoamyl alcohol (0.2 ml of the alcohol dissolved in 10 ml of the water solution) is added to bring the color intensity of the Mo-ferric thiocyanate complex extracted by isoamyl alcohol to a point within the scale. It is shaken gently for 20-30 seconds.

The molybdenum-ferric thiocyanate complex is also extracted in the separatory funnel, but an additional 0.2 ml of isoamyl alcohol are taken for each 10 ml of the solution. When making calculations no attention is paid to the quantity of alcohol added to compensate for dissolving. After the layers separate out, the water layer is withdrawn and the isoamyl alcohol, together with 3-5 ml of the water part, is transferred to a test tube with a ground glass stopper for comparison with the scale. The comparison should be made within 5-10 minutes.

Reagents

1. Concentrated HCl, sp. gr. 1.19;

2. 10 KCNS — 10 g of KCNS are dissolved in distilled water and brought up to 100 ml;

3. 10% $SnCl_2$ — 10 g of $SnCl_2$ are dissolved in 30 ml of concentrated HCl and brought up to 100 ml within distilled water;

4. 5% $FeCl_3$ — 5 g of $FeCl_3$ are dissolved in distilled water to which 5 ml of concentrated HCl has been added and brought up to 100 ml with distilled water;

5. Isoamyl alcohol;

6. A solution of metaphosphoric acid — 10 g of HPO_3 are dissolved in 50 ml of distilled water, 5 ml of 10% $SnCl_2$ are added and the whole brought up to 100 ml with distilled water.

Boron. After treatment with HCl, the plant ash sample is cooled and dissolved by the addition of 1.0 ml of a 30% hypophosphite solution and 9 ml of concentrated H_2SO_4. The contents of the dish are thoroughly mixed when making the solution. Either 5, 2 or 1 ml of the solution are placed in a test tube with a ground-glass stopper, 0.5, 0.8 or 0.9 ml of 30% hypophosphite are added (to bring the solution to 1.0 ml), the mixture is brought up to 10 ml with concentrated H_2SO_4, and, 1 ml of a solution of quinalizarin in H_2O_4 is added. Comparison with the scale is made after 30 minutes.

To determine the total B content in soils, 5, 2, 1 or 0.5 ml of the filtered solution are placed in a test tube with a ground-glass stopper. In accordance with the volume selected, 0.75, 0.9, 0.95 or 0.97 ml of a 30% solution of hypophosphite is added and the mixture brought up to 10 ml with concentrated H_2SO_4; 1.0 ml of a quinalazarin solution is added after 10 minutes and comparison with the scale is made after 30 minutes.

To obtain a color in the analyzed solution within the limits of the scale (dependent on the boron content) it is essential, as shown previously, to take various quantitities of solution both of plant ash and of soil. Initially, 5 ml are taken, and then, if the color of the solution for colorimetry is too blue for the scale, 2 or 1 ml. Alternatively, one can reduce the sample of ashed plant or soil or dilute by adding 1 ml of a 30% solution of hypophosphite, 9 ml of concentrated H_2SO_4 and 1 ml of a solution of quinalizarin.

Reagents

1. Concentrated, chemically pure H_2SO_4, sp. gr. 1.84;

2. 30% solution of hypophosphite — 30 g of potassium (sodium, ammonium) are dissolved and brought up to 100 ml with distilled water;

3. Quinalizarin in H_2SO_4 — 5 mg of quinalizarin are dissolved in 100 ml of chemically pure H_2SO_4, sp. gr. 1.84.

Control analysis must be made when determining any microelement (especially Zn and B). Blank determinations are made with all the reagents. The value obtained is subtracted from the analytical results of the samples. If the corrections from the control analysis are large, the acids and ammonia must be purified by distillation.

This method of ashing plants with HNO_3 fumes was tested by comparing it with the widely used method of ashing samples in a muffle furnace at 500-550° C. The results are given in Table 4.

Data from determination of the total content of microelements in the soil by our method of dissolving them in acids and by fusion with carbonates are given in Table 5.

Tables 4 and 5 show that the ashing of plants in a muffle furnace and by HNO_3 fumes, as well as fusion of soil with carbonates or acid solutions gave comparable results. The discrepancies do not exceed the error limits in ordinary colorimetric assays.

Conclusions

1. Small quantities of reagents are required when ashing plants and soils with HNO_3 fumes (5-10 ml of concentrated HNO_3 to 5 g of plant sample), no loss of the microelements is observed and the ashing is rapid (2-5 min for 5 g of a plant sample).

2. The method of dissolving soils in acids i also comparatively rapid (1.5-2 hr), does not require a platinum vessel or other special equipment and ensures accurate results.

3. When soils are decomposed in acids rational methods can be used to determine microelements. This would be difficult with soils fused with carbonates, especially when determining B and Mo.

4. The method of determining the microelements Cu, Zn, Mn, Co, Mo and B by the use of a series of standard gradations on a scale speeds up analysis considerably and provides the required accuracy. The discrepancies between the analytical results do not exceed the permitted error of 5%-10%.

5. These methods can be used with success in research and in agricultural practice.

6. It is desirable that the ashing and analysis procedures proposed here be tested extensively

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Table 4

Microelement content of plants (mg/kg) on ashing in muffle furnaces and by HNO_3 fumes

Type of plant	Calcining											
	In a muffle furnace						By HNO_3 fumes					
	Cu	Zn	Mn	Co	Mo	B	Cn	Zu	Mn	Co	Mo	B
Red clover seeds	9,0	41,6	40,0	0,13	0,30	8,0	10,0	42,0	40,0	0,13	0,32	12,5
Pea	9,2	42,6	30,0	0,08	0,20	5,0	9,6	42,0	30,0	0,08	0,20	5,5
Wheat	5,5	21,1	40,0	0,02	0,33	Not det'd.	5,8	21,0	40,0	0,02	0,33	Not det'd.
Oat straw	1,0	18,6	45,0	0,08	0,20	3,0	1,2	19,5	45,0	0,08	0,20	3,5
Corn	4,2	15,7	50,0	0,10	0,50	11,0	4,4	16,0	50,0	0,09	0,50	10,0
"	5,0	24,8	60,0	0,08	0,28	10,0	5,0	23,9	60,0	0,08	0,26	10,0
"	5,4	35,3	66,7	0,08	0,07	18,0	5,5	35,0	65,0	0,08	0,08	17,5

Note: Comma represents decimal point.

Table 5

Total microelement content in soils on fusion with carbonates and when dissolved in acids in mg/kg

Soil samples	Fused with sodium carbonate						Acid solution					
	Cu	Zn	Mn	Co	Mo	B	Cu	Zn	Mn	Co	Mo	B
№ 7 A_0 0—5	6,6	33,3	66,6	0,60	0,49	4,0	6,1	33,0	66,6	0,60	0,49	4,2
№ 7 A_1 5—13	2,5	10,0	66,6	0,25	0,33	2,4	2,8	8,3	66,6	0,25	0,33	2,2
№ 13 A_1 1—13	6,2	9,3	133,9	0,83	0,55	3,1	6,2	10,0	133,0	0,83	0,50	4,5
№ 26 A_1 0—15	4,7	8,3	466,0	1,20	0.52	5,0	4,5	8,3	433,0	1,20	0,58	5,3
№ 31 A_1 1—12	11,3	112,0	1600,0	12,00	1,50	35,0	12,0	115,0	1600,0	12,20	1,55	33,3
№ 39 A_1 0—15	9,3	29,8	400,0	3,33	0,55	10,0	8,7	29,0	400,0	3,30	0,60	13,3
№ 11 A_0 0—10	6,8	28,6	213,0	1,33	0,77	21,7	6,9	25,0	213,0	1,10	0,66	19,8

Note: Comma represents decimal point.

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TWO SOIL PROFILES AT ROTHAMSTED EXPERIMENTAL FARMS

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In the summer of 1958, Academician I. P. Gerasimov visited the Rothamsted Experimental Station, England. He described two soil profiles and took samples for chemical analysis. These were later tested in the biogeochemical laboratory of the Institute of Geography, Academy of Sciences, USSR, by O. A. Chichagova.[1]

The Rothamsted Experimental Station was founded in 1843 when plots for experiments with a continuous wheat crop were laid out (one of the profiles described was taken from such a plot). The Station, which is situated at Harpenden (Hertfordshire), at a height of 122 m above sea-level, has a colder and wetter climate than many other points in the eastern part of England. Mean precipitation and temperature for each month of the year are shown in Table 1.

Almost all the Rothamsted soils have developed on old weathering products of the chalk and Tertiary deposits which overlap the parent material at various depths, and are partially covered by a loess-like clay loam. According to the latest classification (Avery, 10), these soils belong to the group of leached acid-humus soils (brown earths and related soils, brown podzolics) which have either a clearly-defined A(B)[2] profile and have developed on solid rock or non-carbonate alluvia, or a structured B horizon developed on weathered rocks with solid inclusions. Many of the Rothamsted farms, for example Broadbalk, Hoosfield and Park Grass are on flatland and have a soil layer developed on loess-like clay loam. The soils of sloping fields, like Barnfield, Agdell and Great Harpenden, are finer-textured; the soil layer is less thick and chalk can be found to a depth of 2-3 m below the surface. The non-plowed Rothamsted fields are very acid, with a pH of 4.0-5.5; but when they were used for agriculture, chalk was applied, creating a slight reserve (1%-3%) of calcium carbonate and a reaction near neutral in the old plowed soils.

The first soil profile was taken from continuous plowland at the Broadbalk Farm. The history of this famous experimental farm falls into two periods: the first period, from 1843-1925, when the entire farm was regularly harvested, and the second period from 1926 onward when the black fallow system was introduced to combat weeds.

The second soil profile was taken at Highfield, which has been pasture ground for more than 300 years. The profiles of both the meadow and the plowland are given below.

Meadowland. Undulating plain; absolute altitude about 100 m. Meadow, with isolated old

Table 1

Quantity of precipitation and mean temperatures (by months)

Months	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year Total
Quantity of precipitation, mm	61,2	51,6	50,0	52,1	52,6	56,1	69,6	67,6	60,4	79,8	73,2	72,9	747,1
Mean temperature °C, maximum	5,3	6,0	7,9	10,8	15,1	18,5	18,8	17,8	14,6	12,4	10,0	7,0	—
Mean temp., minimum	0,4	0,4	0,1	4,0	6,8	10,4	11,4	10,7	8,0	4,9	2,3	2,3	—

Note: Comma represents decimal point.

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[1] In order to get more precise information on a number of points referred to in this paper, the authors also availed themselves of the opportunity afforded by the visit of the English soil scientist, A. Muir, to Moscow in June 1959.

[2] The symbol (B) is used to denote an illuvial horizon which is not clearly defined.

trees (basswood, chestnut), pasture.

0-15 cm. Brownish-grey clay loam, granular-blocky structure. Pebble inclusions. Densely penetrated by roots. Strongly sodded from surface.

15-40 cm. Greyish-brown clay loam (with pale yellow tinge), with inclusions of silica and pebbles; more grey towards the top, lighter towards the bottom, nutty-blocky structure.

40-70 cm. Rich-brown, clay, with rusty mottlings, pebbly, weakly gleyed.

70-100 cm. Clay with pebbles and silica, brown, signs of gleyzation.

From morphological indications, the soil belongs to the group of brown forest, podzolized, weakly gleyed and strongly sodded soils.

As the chemical analysis data show (Table 2), this soil has an almost neutral reaction from the

Table 2

Hygroscopic moisture, pH, total humus and exchangeable cations in meadow soil

Depth, cm	Hygroscopic moisture, %	pH		Total humus, %	Exchangeable cations	
		Water	Salt		Ca^{++}	Mg^{++}
					Meq	
0—10	3,23	6,9	6,16	7,20	31,15	1,78
15—25	2,01	6,1	5,10	2,90	10,22	1,23
50—60	3,05	5,7	4,70	0,52	11,56	0,59
90—100	3,61	5,74	4,49	0,52	12,82	0,89

Note: Comma represents decimal point.

Table 3

Humus content and composition of meadow soil, %

Depth, cm	Total humus	C	N	Humic acids	Fulvic acids	Remainder
0—10	7,20	4,17	0,47	23,3	18,4	39,5
15—25	2,90	1,68	0,22	15,5	23,0	26,2
50—60	0,52	0,30	0,10	4,4	15,9	55,5
90—100	0,52	0,30	0,09	4,0	20,6	56,6

Note: Comma represents decimal point.

Table 4

Particle-size analysis of meadow soil, %

Depth, cm	Diameter of separates, mm						Pre-treatment losses from HCl
	1—0,25	0—25—0,05	0—25—0,01	0,01—0,005	0,005—0,001	<0,001	
0—10	1,62	19,37	39,13	1,65	5,44	25,35	6,83
15—25	1,62	19,58	92,43	2,0	15,87	16,24	2,26
50—60	1,35	10,16	39,56	13,49	10,96	17,63	6,90
90—100	0,76	13,18	39,09	11,95	5,44	27,60	4,98

Note: Comma represents decimal point.

Table 5

Total chemical composition of meadow soil and its colloidal fraction, in % of ignited basis

Sample	Depth, cm	Ignition loss	SiO_2	R_2O_3	FeO_3	Al_2O_3	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{Fe_2O_3}$	$\frac{SiO_2}{Al_2O_3}$
Soil	0,10	10,67	80,80	15,16	3,42	11,74	9,78	63,8	11,5
	15—25	5,63	83,69	14,28	3,83	10,96	10,85	66,1	13,0
	50—60	3,68	76,70	20,18	4,96	14,63	7,29	40,9	8,88
	90—100	3,63	80,82	18,91	4,27	14,64	7,88	49,6	3,37
Clay fraction	0—10	19,11	62,96	32,50	8,63	23,87	3,61	19,2	4,44
	15—25	12,22	52,38	40,73	10,78	28,95	2,14	13,9	2,93
	50—60	9,83	50,91	45,28	13,46	31,82	2,14	10,1	2,72
	90—100	10,46	52,96	45,76	10,56	35,20	2,14	13,3	2,55

Note: Comma represents decimal point,

surface (water pH 6.9, salt pH 6.16), becoming weakly acid further down. It has a considerable accumulation of humus and a fairly high content in exchangeable calcium and magnesium ions.

The so-called sodding process, resulting from the action of grasses, is clearly expressed in the soil profile, and provided the conditions for considerable humus content and biological accumulation of bases. The strongly sodded character of the upper part of the soil has also affected the humus composition (Table 3). Fulvic acid, a sign of forest soil formation, predominates in the profile as a whole, but in the top soil humic acids are found in greater amounts. They apparently formed as a result of the annual addition of organic matter (decomposing roots and stems) from the grasses.

Intensive humification of the topsoil (0-15 cm) appears to have caused a higher colloidal clay content, although a distinct translocation of the colloidal clay with its accumulation at a depth of 90-100 cm can be seen in the soil profile as a whole (Table 4). This may indicate that podzolization processes are developing.

As the total analysis data show (Table 5), an accumulation of SiO_2 and a decrease in the R_2O_3 content are observed in the surface soil; this can also be seen distinctly from the total analysis data for the colloidal clay fraction.

The total analysis data therefore show that signs of podzolization are present, accompanied by a decomposition (in the topsoil) of colloids (<0.001 mm in diameter), an accumulation of residual SiO_2 here, and a transfer of decomposition products (R_2O_3) into the underlying illuvial horizon. The given analysis fully confirms the morphological diagnosis made in the field.

The second profile studied was taken from plowland from one of the Broadbalk plots, which has been under continuous wheat for 115 years.

The morphological description of this profile is as follows:

0-20 cm. Plowed layer, grey-brown, fine clay loam, cloddy to blocky structure with silica fragments.

20-100 cm. Rich brown (greyish in the upper part), gleyed clay with rusty mottlings, silica and pebbles.

From the morphological indications and the conditions of its occurrence, this soil was known in the field as old plow, eroded, brown forest weakly gleyed soil. Owing to erosion and the excessive plowing of the topsoil it has a structure unlike the previous profile, despite its proximity.

Table 6

Hygroscopic moisture, pH, total humus and exchangeable cations in a cultivated soil

Depth, cm	Hygroscopic moisture, %	pH		Total humus, %	Exchangeable cations	
		Water	Salt		Ca^{++}	Mg^{++}
					Meq	
0—20	1,71	6,85	6,90	1,70	15,67	0,44
20—30	3,22	6,60	6,2	0,95	15,75	0,41
90—100	5,04	6,30	5,50	0,73	20,41	1,06

Note: Comma represents decimal point.

Table 7

Particle-size analysis of cultivated soil, %

Depth, cm	Diameter of separates, mm						Pre-treatment losses from HCl
	1–0,25	0,25–0,05	0, 0,5–0,01	0,001–0,005	0,005–0,001	<0,001	
0—20	2,51	22,37	24,36	25,11	9,10	13,99	2,51
20—30	1,54	33,94	21,83	24,06	5,81	8,04	4,78
90—100	22,08	2,28	23,1	7,39	3,57	40,23	1,35

Note: Comma represents decimal point.

Table 8

Content and composition of humus in cultivated soil, %

Depth, cm	Total humus	C	N	Humic acids	Fulvic acids
0—20	1,70	0,96	0,16	14,6	13,6
20—30	0,95	0,55	0,11	4,0	17,8
90—100	0,73	0,43	0,12	3,0	25,0

Note: Comma represents decimal point.

As shown in Table 6, the reaction of this soil is nearer to neutral than that of the first soil, although the pH in the surface soil varies within the same limits (6.0-6.75). The humus content in the arable horizon (1.70%) is appreciably lower; this is obviously due to the continuous cropping of this plot and to the fact that the lower horizon, poor in organic material, has been plowed up to the surface. The content in exchangeable cations (Ca^{++} and Mg^{++}) in the surface soil is relatively low, but increases with depth. The surface horizon is considerably poorer in the clay fraction than are the other horizons. The particle-size analysis data indicate a distinct transfer of the clay and its accumulation in the lower part of the soil profile (Table 7).

Finally, the data for the group composition of organic matter indicate the predominance of fulvic acids in the old cultivated soil (Table 8).

Therefore, in chemical properties the Rothamsted soil which has been under cultivation for a long time is markedly different from the pasture. The profile shows no signs at all of the sodding process, that is, the humus content and exchangeable cations in the surface horizon under the influence of biological accumulation (sod formation). Only one feature is common to both profiles: the transfer of clay particles from the surface to the lower part of the soil profile. As we noted previously, the transfer of clay and the total chemical composition of the soil in the profile of the pasture soil indicate that it is being podzolized.

The profile of the old cultivated soil presents a totally different picture. According to the chemical analysis data of the soil layers (Table 9), there is a clear distinction between the cultivated layer (0-20 cm) and the layers below it. This difference, however, lies in the chemical composition of the colloids. Their content both in silica and in sesquioxides presents a completely monotonic picture; i.e., the composition of the colloids throughout the profile is uniform. The only explanation is that the fine fractions have migrated in the soil profile without deep decomposition and without removal of decomposition products.

Table 9

Total chemical composition of cultivated soil and its clay fraction, in % ignited soil

Depth, cm	Ignition loss	SiO_2	R_2O_3	Fe_2O_3	Al_2O_3	$\frac{SiO_2}{R_2O_3}$	$\frac{SiO_2}{F_2O_3}$	$\frac{SiO_2}{Al_2O_3}$
0 - 20	3,94	85,73	12,27	3,76	8,49	12,10	61,7	17,1
20—30	4,18	73,78	21,17	4,98	16,19	6,50	39,7	7,80
90—100	5,22	69,37	21,34	6,29	15,05	6,15	29,5	7,77
0—20	13,46	49,66	45,53	13,78	31,75	2,09	9,76	2,68
20—30	10,69	50,51	46,01	14,46	31,55	2,10	9,33	2,72
90—100	10,50	50,44	46,97	12,92	34,05	2,02	10,40	2,51

Note: Comma represents decimal point.

On the basis of the data, therefore, the soil can be described as an old cultivated eroded brown forest gley-like soil with clear indications of translocation of non-decomposed clay.

It is well known that the remarkable experiments in the continuous plowing of the soils, single-crop, the application of various fertilizers and other methods used at the Rothamsted Experimental Station have yielded valuable material for agronomy and have given Rothamsted worldwide renown. From the standpoint of soil science, far less attention has been accorded the results, yet the observations, as given previously, show that in this respect there have been outstanding achievements.

A study of the profile of the former forest soil which has been meadowland for 300 years, shows a completely regular pattern of variation in its properties. Firstly, this soil has so far kept its most conservative features, acquired under the influence of forest vegetation, i.e., signs of the development of podzolization. This is shown in the decomposition of the mineral part (in the surface horizon) of the soil mass and in the downward migration of the decomposition products in colloidal form. Secondly, this soil has, over the last 300 years, acquired very pronounced signs of the development of a secondary sodding process, occurring under the influence of grasses, and consisting in a large content of humus (humic composition) and exchangeable cations. These are obviously transferred as a result of the biological cycle.

A study of the profile of the old arable soil at Rothamsted is even more rewarding. Its natural genetic profile has been deeply deformed as a result of a century of excessive continuous plowing. Owing to gradual erosion from the denuded surface, the uppermost (podzolized) horizon has been removed and the underlying layer brought up to the open surface; this surface has been subjected to mechanical mixing, breaking up and the continuous action of filtrated waters. The latter has caused a redistribution of the fine colloidal clay particles in the artificially exposed layer of the illuvial horizon. A considerable proportion of these particles have migrated from the upper layer to the lower. This migration has been caused by purely mechanical means. Such "desilting" or "decolmatation" has given the old cultivated soil the pseudopodzolic profile now known in Western Europe as "lessivé."

Not long ago, one of the present authors (1) advanced the hypothesis that natural soils of the "lessivé" type are of complex, polygenetic origin. The serious gap in this hypothesis, which was based on comparative geographical observation, was the lack of direct experimental information to demonstrate that the formation of a pseudo-podzolic profile through the mechanical migration of clay suspensions was possible, given certain water conditions and physical properties of the soil layer. The foregoing information shows that just such an experiment seems to have been made on the old cultivated soil at Rothamsted and yielded indicative results. The two soil profiles described here are not, of course, sufficient for definitive conclusions on this question, but we regard it as clear that apart from the agricultural practices and chemical experimental material, the Rothamsted Station also has at its disposal interesting material on soil genetics, including the results of scientific experiments on the artificial formation of various types of cultivatal soil. The genesis of such soils is today a particularly urgent problem and it would be difficult to overestimate the scientific value of such material.

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SOIL MOISTURE AND EROSION IN THE HUMID SUBTROPICAL REGIONS OF THE USSR

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Erosion processes are usually treated in connection with such highly important factors as slope, amount and intensity of precipitation, character of the soils and vegetation, agricultural practices, etc. There are few papers about the connection between erosion and the varying moisture of slopes at different periods of the year. Moreover, the fact that different authors have reached diametrically opposite conclusions indicates that there is still a great deal that is not clear on this subject.

It is generally believed (8, 14 et al) that a large amount of surface runoff is formed when heavy rains fall on wet soil; in other words, floods must be preceded by precipitation occurring over several days. Some authors (2), however, believe that for flooding it is necessary that heavy rains fall on "dry" soil after a prolonged drought. Brilinskiy points out that the Transcaucasian eroding floods occur mainly on the very dry southern slopes of the eastern Main Caucasus range.

Daraseliya (4), studying surface runoff and erosion on red earths in the tea and citrus plantations of Anaseuli, concluded that the main soil losses occur during three-fourths of the summer-fall period (August-October), that is, in the period when the soil is driest under the conditions prevailing on the Black Sea littoral of the Caucasus.

Soil moisture can influence erosion in many ways; by altering the structure of the soil, the swelling capacity of the soil particles, the water permeability, the vegetative cover, the microbiological, physical and chemical processes, etc. Sobolev (13) says "there is a marked difference in the erosion resistance of soil that is air-dry and of capillary-moist soil." Gussak (3), studying runoff and erosion on monoliths in Georgia, established that soils tend to erode less the further they are from a low-precipitation zone and the nearer they are to a higher precipitation zone. He refers to similar experiments by Wollny, who found that northern and western slopes are less eroded than southern and eastern ones, since the former are always wetter and their soil cohesion is greater.

Great theoretical and practical importance is now attached to the study of erosion dynamics in relation to soil moisture. Such study can reveal the specific laws of development and origin of erosion, distinguish the types of erosion foun in dry and wet countries, on shady and sunny slopes, in winter and summer (in the tropics and sub-tropics) and in different years according to the degree of moisture. At the same time such study can make it easier to combat erosion and forecast the effect that weather changes, in regions and areas with different degrees of moisture, will have on the soil erosion.

We give below our findings on the Black Sea littoral of the Caucasus (Sochi District),[1] which illuminate the topic under discussion. The worl was done on yellow-earths podzolic soils in the maritime zone between 1950 and 1953. This zone has the following specific characteristics affecting the development of erosion processes; 1) a large amount of precipitation (1400-1600 mm per year); a peak precipitation (900-1000 mm) and a period of peak diurnal maxima (110-117 mm) occur in the fall-winter period when the soils are saturated and the vegetation cover is poor; precipitation falls on soil which does not freeze in winter, evaporation being negligible in this period; 2) excessively wet fine clay loam subsoil in the fall-winter period leads to their becoming swamped and gleyed, lowers their water permeability and causes runoff on plowed slopes, thereby appreciably increasing surface runoff and erosion during this period; 3) there are no eroding flood-waters or alluvial fans, but fairly heavy floods occur owing to the excessively moist territory and the dense afforestation; 4) there is appreciable drying of the upper layers of the sub soil in the treeless area during the summer, accompanied by the formation of deep cracks and the breaking-up of roots (in fine-textured soils), which, to an extent, inhibits surface runoff at the start of the rainy period; 5) high moisture combined with tempera tures above zero in the course of the year prolong the vegetative period. This causes a certain periodicity in plant development and fosters intensive natural reforestation and the rapid overgrowing of the denuded slopes and gulleys which have formed on cultivated land and pastures.

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[1] The work was done at the Black Sea Experimental Station of Mountain Agriculture of the All-Union Scientific Research Institute of Afforestation.

Table 1

Average percent runoff, depending on time of year and amount of precipitation accompanying rainfall of less than 0.5 mm/min intensity

Runoff Plot Number	Land use	Moisture periods								
		Excess (November-March)			Normal (April, May, October)			Deficient (June-September)		
		20–25	30–45	50–65	20–25	30–45	50–65	20–25	30–45	50–65
		I =0,1 – 0,2			I =0,4 – 0,5			I =0,3	I =0,1 – 0,2	
10	Corn	16,0	20,6	25,3	15,9	31,5	34,7	3,8	1,1	2,7
2	Overgrown with shrubs	12,0	12,4	13,0	10,3	21,9	25,2	2,2	1,1	1,0
1	Forest	18,0	17,9	23,8	12,5	23,6	34,6	3,4	1,4	2,0

Note: The average was taken from 2-3 observations made at short distances on the runoff (with a 2%-5% variation) for the quantity of precipitation indicated (20-25 mm, 30-45 mm, 50-65 mm) and intensity (I).

Note: Comma represents decimal point.

Two basic methods were used to study erosion: 1) observations on natural precipitation falling on unit runoff areas of 75 m^2 (5 x 15 m); 2) sprinkling areas of 10 m^2 (2 x 5 m) at the rate of 1.5-2.0-2.5 mm per minute.[2] The unit runoff areas were situated on the upper third of a southeastern slope with a gradient of 15°; the first was in a sparse oak-hornbeam forest, the second was in an area of dense prickly shrub in the cut-over forest area and the third was in a corn field. Runoff and erosion were observed on permanent plots from October 8, 1950 to January 1, 1953. In Table 1, we have grouped by periods the runoff and erosion data (and partially averaged them) according to quantity and intensity of precipitation and degree of soil moisture.

As Table 1 shows, runoff increases with increase in the amount of precipitation, even when the intensity of the rainfall remains constant. This applies to all land use. The amount of runoff varies greatly, depending on the soil moisture. In the period November-May, when there is excess moisture in the soil, the runoff is appreciably higher (12%-25%) than in the June-September period (1%-3.8 %) when there is a moisture deficiency in the soil. Under "normal" wetting conditions, the runoff values should be intermediate between these extremes; according to our data, however, it proved to be slightly higher than in the excessive moisture period. The reason is that in April, May and October, the intensity of precipitation was twice as great as in the November-March period.

Intensity of precipitation, together with soil moisture, is therefore an important factor in

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[2] This method is described in detail in the paper on "Runoff within the soil under mountain conditions in the humid sub-tropics," Pochvovedeniye, 1957, No. 12.

Table 2

Percent runoff accompanying rainfall of more than 0.5 mm/min intensity

Land use	Moisture periods								
	Excess				Normal			Deficient	
	Intensity, mm/min								
	0,53	0,6	0,7	0,9	—	—	1,1	1,2	1,1
	Amount of precipitation, mm								
	64	44	34	23	134	79,1	41,7	119,9	103
Corn	39,6	43,3	75,0	81,0	45,0	28,0	50,0	30,0	21,0
Shrubs	13,2	19,6	27,3	37,0	6,4	9,0	12,0	7,5	1,5
Forest	37,1	42,0	47,0	49,0	15,0	25,0	35,0	9,0	1,8

Note: Comma represents decimal point.

runoff under natural conditions. The order of the plots in terms of runoff amount (in decreasing order) was as follows: corn, forest, shrub. The slight differences in runoff were due to the poor water-permeability of the plots covered with natural vegetation. In the corn plot, where the soil was loosened annually by plowing, water permeability was 0.5 mm per minute, whereas in the forest it was only one-third of this (0.16 mm per minute). The poor water permeability of soil in the forest is a result of its compaction by cattle-grazing. Nevertheless, the role of vegetation in diminishing runoff can clearly be seen, especially in regard to runoff during heavy rains falling on "dry" soil. Less than 20 mm precipitation falling on "dry" soil in the summer gave no runoff. The runoff, when precipitation was more than 0.50 mm per minute, is shown in Table 2.

Table 2 shows more clearly than Table 1 the influence of the intensity of precipitation and soil moisture on surface runoff. As moisture diminishes from winter to summer, the runoff from rain decreases; in other words, the amount of precipitation of a given intensity falling on "dry" soil in summer and causing runoff is appreciably higher than the corresponding amount causing runoff falling on wet ground in winter. The amount of runoff and the probability of its formation in the cold period is considerably higher than it is in summer. In order to estimate the effect of winter and summer rains in causing runoff, we shall compare the mean values for runoff associated with two rainfalls of similar intensity and quantity in winter (intensity 0.53 and 0.6 mm per minute) and two in summer, of twice the intensity and double the amount (intensity 1.1-1.2 mm per minute).

Table 3

Average percentage runoff in winter and summer

Land use	Winter, precipitat. 54 mm, int. 0.56 mm/min	Summer, precipitat. 111.4 mm, int. 1.5 mm/min
Corn	41,4	25,5
Shrubs	16,4	4,5
Forest	39,5	10,4

Note: Comma represents decimal point.

As Table 3 shows, the capacity of winter rains to cause runoff (if we arbitrarily assume the winter precipitation to have the same intensity and magnitude as the summer rains) is almost four times greater than that of summer rains on the corn field and eight times greater on the forest and shrub plots. Similarly, if we compare rainfall of low intensity (0.1 and 0.2 mm per minute) and slightly smaller quantity (30-65 mm, Table 1), we see that the ability of low intensity summer rains to form runoff is one-twelfth that of winter rains on all the land use. Such is the role of soil moisture (seasonal).

Soil temperature undoubtedly also plays an important part in forming surface runoff, but, unfortunately, we were unable to consider its influence.

In regard to runoff, the period of "normal" moisture occupies an intermediate position between the extreme moisture periods. Table 2 indicates that when precipitation is appreciable (more than 20 mm per day), especially in winter, the amount of runoff is determined mainly by the intensity of the precipitation. The greater the intensity of precipitation, the greater the amount of runoff. The role of vegetation (shrubs and forest) in reducing surface runoff during rainfall of high intensity (more than 0.5 mm per minute) is as marked as it is in the case of low intensity rainfall, although, as noted previously, plots with vegetative cover also have a lower water-permeability than plowed plots. Vegetation is particularly effective in reducing runoff during the summer, when the runoff in the shrubs and forest is 1/3 to 1/4 of the runoff in the field.

The distribution of runoff in the plots is the same as in the case of low intensity rains (Table 1): corn field, forest, shrubs, in

Table 4

Soil erosion, kg/ha with rainfall of less than 0.5 mm/min

Precipitation; land use	Moisture periods								
	Excess (November-March)			Normal (April, May, October)			Deficient (June-September)		
Precipitation intensity, mm/min	0,1—0,2			0,4—0,5			0,3	0,1–0,2	
Precipitation, mm	20—25	30—45	50—65	20—25	30—45	50–65	20—25	30—45	50—65
Corn	25	150	227,0	51,0	75,0	158	3,7	1,6	2,0
Shrubs	3,4	3,1	3,7	3,2	7,2	—	0,5	—	—
Forest	5,2	6,0	11,0	8,4	9,2	27,9	0,6	0,3	—

Note: Comma represents decimal point.

sparse forest therefore serves as better protection from erosion than sparse forest (density 0.3) with slight undergrowth where there is cattle grazing.

Tables 4 and 5 give data for erosion on permanent runoff plots for the period October 8, 1950—January 1, 1953.

As Table 4 shows, soil erosion, like runoff (Table 1), increases with an increase in the amount of precipitation. This is particularly marked on cultivated land. Erosion diminishes from the period of excess moisture to the period of moisture deficiency; in other words, the amount of erosion in winter is greater than in summer. The slightly higher values for erosion in the period of "normal" moisture are explained by the greater intensity of precipitation.

A few examples will show how soil moisture influences erosion. The erosion accompanying 44.1 mm of rain which fell on wet soil on March 22-23, 1951 was as follows: cultivated land 495 kg/ha, shrub growth 14.5 kg/ha, forest 47.7 kg/ha. The corresponding figures for the rainfall on April 17-18, 1951, which was nearly twice as much (79.1 mm) were 116-, 12- and 37-kg/ha. Erosion accompanying the 103 mm rainfall of August 1, 1951 (on "dry" soil) was as follows: cultivated 44 kg/ha, shrub 1.2 kg/ha, forest, 1.4 kg/ha; 119.9 mm of rainfall of the same intensity which fell on wet soil on August 2-4, 1951 caused, respectively, 102 kg/ha, 1.5 kg/ha, and 30 kg/ha of soil erosion. The erosion on the corn field was thus 75% greater when precipitation of an intensity of less than 0.5 mm per minute fell on wet soil than when similar precipitation fell on "dry" soil. On soils with a three-shrub cover, on the other hand, the degree of moisture has little influence on erosion although, as we saw previously, runoff may be even greater. This is due to the firm cohesion of forest soil particles and the fact that they are protected from dispersion by vegetation and litter.

Table 5

Soil erosion, kg/ha with rainfall of more than 0.5 mm/min

Precipitation; land use	Moisture periods											
	Excess (November-March)				Av.	Normal (April, May, Oct.)			Av.	Deficient (June-Sept.)		Av.
Amount of precipitation, mm	64	44	34	23	—	134	79,1	41,7	—	119,9	103	—
Intensity of precipitation, mm/min	0,53	0,6	0,7	0,9	—	?	?	1,1	—	1,2	1,1	—
Corn	79,0	495,0	300,0	396,0	317,0	227,0	116,0	145,0	162,0	102,0	44,0	73,0
Shrubs	4,8	10,5	9,0	22,7	12,7	20,5	12,0	5,4	12,6	1,5	1,2	1,3
Forest	15,8	47,7	25,5	30,0	29,0	34,5	37,0	18,1	29,8	30,0	1,4	15,7

Note: Comma represents decimal point.

If we turn now to the data for erosion accompanying precipitation of an intensity greater than 0.5 mm per minute (Table 5), we see that average soil erosion, by seasons of the year, will be considerably greater again in the corn season, but not in the forest and shrubbery areas. As in the previous case, soil erosion sharply increases from the period of moisture deficiency to the period of excess moisture. The higher total erosion in winter is explained by the greater absolute runoff during this period and the considerable leaching of soluble compounds which increase the turbidity of the runoff. Moreover there were few rains during the summer observation periods. The absolute values for soil erosion accompanying precipitation of an intensity of more than 0.5 mm per minute are noticeably higher than those for precipitation intensity of less than 0.5 mm per minute.

From the data in Table 6, it follows that with 1 mm of runoff-forming precipitation the soil eroded, on the average, 2.32 kg/ha in the corn field, 0.2 kg/ha in the forest and 0.06 kg/ha in the shrubbery growth; consequently, the intensity of erosion in the forest was one-eleventh and in the shrub one-thirtyeighth of that in the corn field.

Table 6

Total soil erosion, kg/ha

Land use	In 12 months Oct. 3,1950 - Oct. 15, 1951, precipitation 1313.3 mm	In 8 months Apr. 12, 1952 - Dec. 30, 1952, precipitation - 697.6 mm
Corn	1526	1492
Thorny shrubbery growth	153,8	12,9
Forest	450,6	72,7

Note: Comma represents decimal point.

Table 7

Turbidity of run-off, g/liter

Place of taking samples	Precipitation, spring-summer period: June 12, 1950 83.2 mm in 30 min	July 12, 1950 106.2 mm in 3 days	May 8, 1951 29.2 mm in 6 hours	May 19, 1952 134 mm in 2 days	Winter period during snow thaw and steady rain
Kholodnyy brook, wooded part of area	1,4	0,12	0,16	0,24	0,31
Kholodnyy brook, sparsely wooded part of catchment area	32,0	1,07	3,18	5,16	1,17
Corn	10,68	0,39	1,82	2,54	2,20
Sparse forest without litter	0,64	0,34	0,15	0,14	0,74
Dense growth of thorny shrubs with litter, 2-3 cm thick	0,14	0,03	0,06	0,08	No runoff

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[a]Rainfall intensity up to 1mm/min.

Note: Comma represents decimal point.

Table 8

Runoff and soil erosion with sprinkling on "dry" and wet soil (rainfall 2.5 mm/min)

Land use	Slope, degrees	Moisture condition of soil	Amount of precipitation, mm	Runoff, % of precipit.	Soil erosion, kg/ha
Fallow, compacted	12	Dry	37,5	13,4	2082
		Wet	75	80,5	711,5
Fallow, compacted	20	Dry	72,8	1,4	26,2
		Wet	37,9	58,5	625,0
Fallow, compacted	25	Dry	150,5	49,8	12927
		Wet	158,0	75,2	9488
Shrubbery growth	12	Dry	75,0	22,0	27,9
		Wet	150,0	64,5	53,5
Shrubbery growth	19	Dry	120,0[a]	32,6	None
		Wet	120,0[a]	45,4	7,1
Shrubbery growth	24	Dry	150,0	None	None
		Wet	148,0	16,3	12,0
Forest without litter	20	Dry	155,0	0,7	13,2
		Wet	156,0	6,0	30,4
Forest without litter	25	Dry	146,0	35,5	1683,0
		Wet	152,0	86,0	654,0
Cut-over forest	20	Dry	161,0	38,0	1412,5
		Wet	150,0	51,3	730,0

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[a]Rainfall 2.0 mm/min.

Note: Comma represents decimal point.

The following results (see Table 7) were obtained from determining the turbidity of the surface runoff accompanying natural precipitation on different land use in summer and winter.

The figures show that the influence of soil moisture on erosion varies according to the force with which the precipitation falls, the land use and the condition of its surface. The influence of moisture on erosion is slight on forested soils with good water permeability, although we find it increasing slightly as soil moisture and intensity of precipitation increase. The plowed plots erode considerably when heavy rains fall on "dry" soil, while erosion accompanying low intensity precipitation is greater in winter than in summer.

Tables 8, 9 and 10 show the influence of soil moisture on runoff and erosion under sprinkling conditions.

Table 8 shows that surface runoff is everywhere higher on "wet" soil, given the same or

Table 9

Variation in erosion depending on total increase in sprinklings during following sprinklings

Land use	Slope, degrees	Amount of sprinkling, mm (intensity 2.5 mm/min)	Runoff (% of precipitation)	Soil erosion, kg/ha
Fallow	12	37,5 on dry soil	13,4	2082
		75 after 187.6	61,5	1289
		75 after 262.6	80,5	711,5
Fallow	20	72,8 on dry soil	1,4	26.2
		156,0	38,2	2910
		60,0 (intensity 2.0)	59,1	891
		37,9	58,5	625
Fallow	25	150 on dry soil	49,8	12927
		158 after 259.4	75,2	9488
		150 after 376.5	69,0	2281
Shrubbery growth, removed prior to sprinkling	19	153 on dried soil	71,0	1784
		155 after 579	88,0	600
Same plot when spaded	19	157 on dry soil	None	None
		152 after 582	5,2	13,3

Note: Comma represents decimal point.

even smaller amounts of sprinkling, than on "dry" soil, whereas erosion varies according to the condition of the surface. Less erosion is observed on fallow plots and cut-over forests when precipitation is heavy on "wet" soil than when it falls on "dry" soil. This is due to the accumulation of loose particles in the topsoil of fallow fields and freshly cut-over forest land, formed during the drying, weathering, and in the case of cut-over areas, stripping of the soil surface. On the re-growth and forest plots without litter, where the soil surface is undisturbed and the vegetation protects it from dispersion by raindrops, more erosion occurs when rain-drops fall on wet soil than when they fall on "dry" soil. The protection which vegetation gives against cracking, weathering and dispersion of soil in the dry condition (because the accumulation of loose particles that can be shifted with the water is negligible) is of great importance in reducing the immense amount of erosion which usually occurs on plowland when heavy rains fall on "dry" plowed soil. It must be noted, however, that such rains do not in all cases cause more erosion that they do falling on wet soil. When,

Table 10

Minimum amount of water forming runoff (mm) depending on soil moisture from sprinkling

Land use	Slope, degrees	Soil			
		Dry		Wet	
		Intensity of precipitation, mm/min			
		1,5	2,5	1,5	2,5
Fallow, compacted	12	25	15,0	1,5	1,0
Fallow, compacted	20	Not det'd.	41,0	5,8	4,7
Plowed, covered with weeds, compacted	18	4,5	3,5	1,0	0,5
Plowland, loose	19	>300	150,0	Not det'd.	27,5
Forest with litter	20—25	Not det'd.	>300,0	"	>300,0
Shrubbery and grass	19	"	12,5	4,5	4,0
Shrubbery and grass	24	"	17,5	5,0	3,0

Note: Comma represents decimal point.

for example, rain falls on "dry" weakly-compacted, furrowed plowland, there may be no erosion: 265 mm of rain fell at the rate of 2.5 mm per minute for 105 minutes on such plowland (a plot overgrown with weeds and with a 19^0 slope) in the "dry" and wet conditions, and erosion occurred only on the wet soil (185.8 kg/ha).

As we see from Table 9, sprinkling at a constant rate on wet soil after a number of previous rains of varying intensity and duration causes an increase in the total runoff and a decrease in erosion. The maximum erosion in all cases occurs mainly during the first third of the sprinkling period.

An important aspect of this question is to know the critical intensities and quantities of precipitation which can cause runoff and erosion on soils of varying degrees of moisture.

As we see from Table 10, the minimum amount of sprinkling causing runoff from wet soil is appreciably lower than on "dry" soil, the absolute values for critical precipitation being very high for soils with good water permeability (forest, loose plowland). The high water permeability of loose plowland, on the other hand, decreases sharply with increase in moisture and compacting as a result of rain drops. Increased wetting of forest soils with good water permeability, on the other hand, does not lead to any notable lowering of the critical values for sprinkling causing runoff, owing to the high rate of intake into the soil.

Observation has established that natural precipitation of less than 20 mm per day falling during the spring-summer period on "dry" soil, gave no runoff either in the forest or in the plowed row crop plots, whereas in winter such precipitation always caused slight runoff. The critical rate of runoff formation in winter on plowland corresponded to a precipitation rate not exceeding 0.05-0.1 mm per minute; the corresponding figure in summer being more than 0.5 mm per minute. The nature of the erosion processes on the Black Sea littoral is therefore different in winter than in summer. In winter, there is gradual, barely-noticeable erosion in the form of continuous, very thin films of soil, which continues sluggishly, for a long time, whereas in summer the erosion processes operate considerably less frequently over shorter periods and have greater destructive force, forming, in the main, stream wash-outs, rills and floods.

In conclusion, it should be noted that the influence of soil moisture on erosion and runoff varies according to the intensity of the rainfall, the type of land use and the condition of the soil surface. Surface runoff is in all cases greater when precipitation falls on wet soil, as confirmed by the observations of Kocherg (8), Tkachenko (14), and others. It follows that surface runoff on moist soil can form as a result of less intensive and steady rainfall than is needed to form runoff on "dry" soil; that in the humid conditions of the sub-tropics, runoff is greater in winter than in summer and can be caused by rains which would not cause it in summer; that in wet years surface runoff is always greater, other conditions being equal, than in dry years. Therefore, in this sense, it can be said that floods are preceded by precipitation lasting ove a certain period of time.

Concerning the influence of initial soil moisture on erosion, a number of specific characteristics appear. In good soil structure, covered with dense vegetation, the degree of wetting has little influence on erosion, which hardly occurs at all on such land. On soils subject to erosion—structureless, old cultivated soils denuded of vegetation owing to deforestation and excessive cattle grazing—an immense amount of soil is eroded when heavy, steady rains fall on to "dry" soil. This is because a large amount of loose, fine-grained material, easily eroded by water, accumulates on the surface of such soil during weathering. This is again supported by observation of the sprinkling results on such plots at a rate of 1.5-2.5 mm per minute, when the amount of erosion, other conditions being equal, is a great deal less after the final sprinklings than it is after the initial sprinkling. Slight rainfall (up to 20 mm) falling on "dry" soil that is subject to erosion causes neither runoff nor erosion, but both occur when slight rain falls on wet soil. Gussak's (3) conclusion, that soils in a low moisture zone are inclined to erosion, therefore agrees with our own findings and those of Wollny's; that soils on northern and western slopes hold together better and are less liable to erode than soils on eastern and southern slopes, which have less moisture. Similar observations have been made by Daraseliya (4). Brilinskiy's contention (2) that floods are formed when heavy rains fall on "dry" soil, does not agree with the observations of other investigators; this, we think, may be because Brilinskiy has not traced the course of precipitation in catchment areas.

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THE TITANIUM CONTENT IN SOILS OF THE YAROSLAVL REGION[1]

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In terms of the amount contained in soils and in the lithosphere, titanium is halfway between a macro- and a microelement. It is one of the elements occurring fairly commonly in nature. It makes up 0.6% (weight) of the Earth's crust. Different rocks contain different quantities of Ti: granites, 0.23%; basalts, 0.90%; nepheline-syenites, 0.80%; the average Ti content in magmatic rocks is 0.44% and in argillaceous-sandstone sedimentary rocks, 0.45% (3). Basic rocks are richest in Ti, acid rocks considerably less rich. The Ti distribution in rocks, such as we have described, is strongly reflected in the Ti content of soils, waters, vegetation and animal organisms.

The Ti content in soils varies greatly, depending on the type of soil-forming rocks and the trend of the soil-forming processes. Different lowland soils in the USSR contain 0.10%-0.80% Ti. Table 1 shows the Ti content in soils.

Ti content in river water is of the order of $9 \times 10^{-7}\%$ to $2.5 \times 10^{-6}\%$. The Ti content in animals varies between $n \times 10^{-3}\%$, and $n \times 10^{-4}\%$.

Vernadskiy (1, 2) notes that organisms concentrate Ti in quantities of 100-1000 times greater than the average.

The Ti content in plants depends both on the amount of Ti in the soil and on the species of the vegetation itself (selective absorption of Ti by different plants). Vegetation contains more Ti than living organisms (live weight). The average Ti content in the human being is 0.02 mg per 100 g live weight.

In mammals, Ti has been found to accumulate primarily in the horns and hair; in birds, primarily in the feathers. This element is a constant component of milk. Its metabolism in organisms has been insufficiently studied; its biological role has not been explained to this day (4). Polynov (7) also notes that the physiological role of Ti has hardly been studied at all as yet. Its wide distribution in organisms is a direct consequence of its presence in practically all rocks, weathering crusts, and soils. Polynov notes that the Ti found in weathering crusts plays only a very small part in the biological cycle, but considerable bodies of it remain in a slightly available form of primary minerals (rutile, ilmenite) and in the form of stable secondary formations.

According to Vernadskiy (1, 2), Ti is characterized by its own very peculiar type of primary compounds. It is found in rocks either in the form of titanates (Ca, Fe, more rarely Mg) or as part of complex compounds with SiO_2 (sphene) and Fe_2O_3, or else in admixture with various primary silicates and alumosilicates; more rarely, it forms part of complex rare earth compounds. Finally, it can be found in free oxide form (TiO_2).

Sedletskiy (10) has established that in a zone of hypergenesis, Ti is distinguished by considerable migration (sedimentary rocks and continental deposits), developing in the process of the rock formation. He believes that the loss or accumulation of Ti in a hypergenesis zone depends on the nature of the rock-weathering processes. The Ti content in colloidal fractions of soils and clays is appreciably higher than in coarser fractions.

Polynov and Tumilovich (71), Vinogradov (3), Kaminskaya (5), Sinyagin (9), Troitskiy (11), and a number of other investigators have established that the Ti content in soils gradually increases down the profile (from the humus horizon to the parent material). This applies to podzols, grey forest soils, sierozems and other soils. In red earths, the Ti content is often found to have a higher content in the upper horizons.

There is a good deal of information in the Ti content in podzolic soils. Porfir'yev (8) found 0.30%-0.32% Ti in podzolic soils on loess-like clay loams; Kaminskaya (5) found 0.38%-0.48%; Nogina (6) found 0.05%-1.00% (average 0.39%) Ti in the podzolic soils of the mountain part of the Central Urals, the amount depending on the Ti content in the parent material. Vinogradov (3) gives the mean Ti content in podzolic soils as 0.38%; American podzolic soils contain 0.28%-0.95% Ti (13).

In order to determine the Ti content in the

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[1] The work was done in the soil chemistry laboratory of the Soil Institute of the USSR Academy of Sciences under the direction of V.A. Chernov.

Table 1

verage Ti content in different soils (%) (from A. P. Vinogradov)

Soil	Ti	Soil	Ti
'eat bogs (tundra)	0.52	Chernozems	0.45
'odzolic	0.38	Chestnut	0.41
irey forest	0.44	Sierozems	0.21
		Red earths	0.71

Table 2

Average Ti content in soil-parent materials of the Yaroslavl region, %

Parent material	Ti	Samples	Range
Clay loam deposits	0,326	55	0,216—0,594
Boulder clay loam	0,282	26	0,196—0,368
Sandstone	0,159	10	0,072—0,230

Note: Comma represents decimal point.

oils and soil-forming rocks of the Yaroslavl egion, we analyzed some 300 samples.[2] The nalyses were made by photocolorimetry (after ecomposing the soil or rock samples with nhydrous hydrofluoric acid) of the Ti yellow btained through the action of hydrogen peroxide a weakly-acid medium (5% H_2SO_4) on the olutions under study. The samples used for nalysis were sod-podzolic soils under diferent types of vegetation (forest, cultivated, eadow) developed on deposits and boulder lay loams and sandy loams and also on sandtones.

The type of the parent material and its Ti ontent considerably influence the Ti content soils (Table 2). The Ti content is highest clay loam, medium in boulder clay loam nd lowest in sandstones.

Titanium Content in Sod-Podzolic Soils Under Forest Vegetation

Considerable differentiation of the soil rofile on the genetic horizon is characteristic the Yaroslavl region sod-podzolic soils rmed under natural forest vegetation (sprucexalis, occasional spruce with birch, alder, spen, larch forests, and pine forests on sandtones). Appreciable migration of soluble and olloidal substances from the upper part of the profile, followed by their concentration in its deeper parts, occurs during the process of soil formation. Let us examine how the soil-formation process influences the Ti content in soils under forest (Table 3).

The data shown in Table 3, together with other analytical material on the Ti content in the region's sod-podzolic soils not given in this paper (26 profiles in all) were used to calculate the average Ti content in soils under forest vegetation (Table 4).

As Tables 3 and 4 show, the Ti content in the sod-strongly podzolic soils under spruce and spruce-larch forests formed in this region on clay loam (profiles 60, 103, 104, 128, etc.) gradually increases down the soil profile, the lowest content being in the upper part of the profile and particularly in horizon A_0 and the highest content in the parent material. No marked differentiation in the Ti content in the genetic horizons is observed. In some cases, a slight decrease of the Ti content can be noted in the A_2 as compared with the A_1 horizon (profiles 60 and 103) and a very slight increase in the B horizon (as compared with the parent material – profiles 60 and 104). There is migration of the Ti from horizons A_0, A_1 and A_2, where the Ti content is lower by factors of 1.6, 1.1 and 1.02, respectively, than in the parent material.

In sod-strongly and moderately podzolic soils under spruce-bilberry-oxalis on boulder clay loam (profiles 117, 119 and others), the Ti content throughout the profile diminishes slightly in comparison with the profile on clay loam. This is apparently due to the fact that the rock and the soils formed on it are relatively uniform and are of coarser texture, as well as to the lower Ti content in the rock. In these soils, the Ti content in horizons A_0, A_1 and A_2 is lower than in the parent material by factors of 2.23, 1.27 and 1.2, respectively (Table 4).

In sod-podzolic-gley soils developed on sandstone (profiles 113, 114 and others), the upper part of the profile is again notably poor in Ti. This is particularly marked in the soil of profile 114, which developed on a two-layered alluvium and in which horizons A_0, A_1 and A_2 contain a very slight quantity of Ti owing to the sandiness of this part of the profile, whereas there is a very great increase in the Ti content in horizons in B_2 and BC (3.5-4 times more), partly owing to the finer texture of this part of the profile (on moraine) and principally because this itself is largely due to the considerable gleization of these horizons. In profile 113 there is even some accumulation of Ti in horizons A_0, A_1 and A_2 in comparison with the parent material, probably because this profile is somewhat peaty and the Ti is consolidated in the form of an organic-mineral complex. The lower sandy horizons are poorer in Ti.

The mean Ti content in the profile of sandy sod-podzolic soils (Table 4) is almost 1.5-1.8 times lower than in soils on boulder and clay loam deposits. In comparison with the parent material, however, there is a relative increase in the Ti content in horizons A_1, A_2 and especially B (the gleyed part) by a factor of 1.35

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[2] The soil survey of the region and the collection of mples were carried out by O.A. Vadkovskaya.

Table 3

Ti content in sod-podzolic soils under forest, %

Sample No.	Horizon	Depth, cm	Ti
Profile 60. Sod-strongly podzolic on fine clay loam deposit over carbonate boulder clay loam. Spruce forest with larch admixtures.			
1	A_0	0—3	0,198
2	A_1A_2	5—15	0,264
3	A_2	23—33	0,240
4	B_2	60—70	0,294
5	BC	95—105	0,282
6	C	145—155	0,258
7	C	330—350	0,242
8	D	480—500	0,228
Profile 103. Sod-strongly podzolic on fine clay loam deposit. Forest: spruce, aspen, birch.			
9	A_0	0—4	0,216
10	A_1	6—9	0,337
11	A_2	15—25	0,298
12	B_1	35—45	0,324
13	B_2	60—70	0,324
14	C	150—155	0,337
15	C	240—260	0,351
Profile 104. Sod-strongly podzolic on medium clay loam depsoit. Forest: spruce-oxalis.			
16	A_0	0—4	0,184
17	A_1A_2	5—10	0,324
18	A_2	12—22	0,351
19	B_1	38—48	0,388
20	B_2	58—68	0,341
21	C	140—150	0,341
22	C	180—200	0,405
23	C	220—240	0,388
24	C	310—330	0,341
Profile 128. Sod-strongly podzolic on coarse clay loam deposit. Larch forest mixed with spruce.			
25	A_0	0—4	0,200
26	A_1	5—10	0,216
27	A_1A_2	12—20	0,292
28	A_2	25—35	0,264
29	B	70—80	0,264
30	C	140—150	0,264
31	C	240—260	0,280
Profile 117. Sod-moderately podzolic on medium boulder clay loam. Forest: spruce-bilberry-oxalis.			
32	A_0	0—5	0,132
33	A_1	8—18	0,246
34	A_2	30—40	0,246
35	B	70—80	0,246
36	C	110—115	0,309
Profile 119. Sod-strongly podzolic on fine boulder clay loam. Forest: spruce-oxalis.			
37	A_0	0—4	0,082
38	A_1	4—6	0,216
39	A_1	8—18	0,238
40	A_1A_2	20—30	0,287
41	A_2	35—45	0,246
42	B	75—80	0,346
43	C	152—157	0,368
Profile 113. Sod-podzolic gley on sand. Forest: pine, mountain cranberry, moss.			
44	A_0	0—8	0,174
45	A_1	8—13	0,222
46	A_2	25—35	0,234
47	B	40—50	0,162
48	C	100—105	0,072
Profile 114. Sod-podzolic gley on a two-layered alluvium (sand, moraine underlay). Forest: pine, spruce, reed grass, bilberry.			
49	A_0	0—4	0,107
50	A_1	5—12	0,096
51	A_2	20—30	0,091
52	B_2	60—70	0,427
53	BC	85—90	0,324

Note: Comma represents decimal point.

on the average.

The data in Tables 3 and 4 accordingly show that in sod-podzolic soils under forest vegetation on boulder and deposits of clay loams, the Ti content gradually increases down the profile, the minimum quantity being found in the A_0 horizon (forest litter) and the maximum in the parent material. The profile richest in Ti is that of forest soils on clay loam deposit;

Table 4

Average Ti content in sod-podzolic soils under forest, %

Horizon	Clay loam deposit		Boulder clay loam		Sandstone	
	Ti	Range	Ti	Range	Ti	Range
A_0	0,195	0,144—0,246	0,133	0,082—0,184	0,128	0,102—0,175
A_1	0,286	0,216—0,341	0,233	0,216—0,250	0,164	0,096—0,222
A_2	0,307	0,240—0,373	0,239	0,224—0,252	0,170	0,091—0,234
B	0,311	0,246—0,388	0,285	0,246—0,346	0,197	0,132—0,324
C	0,314	0,242—0,405	0,296	0,216—0,364	0,131	0,072—0,162

Note: Comma represents decimal point.

the profile of boulder clay loam soils has slightly less Ti and there is still less in the profile of soils on sandstone. This shows that the quantity of Ti in soils depends on the Ti content in the parent materials and the trend of the soil formation as well as on the texture of the soils and the parent materials.

The Ti content in different types of forest litter depends very little on the species of vegetation but more on the texture of the soil and the parent material.

Titanium Content in Cultivated Soils

The cultivation of sod-podzolic soils previously under forest leads to some changes in their physical, chemical and morphological properties. The A_2 horizon, which in forest soils is very distinct, stands out less distinctly in cultivated soils and often falls to a lower level, while the cultivated layer becomes less acid under the influence of field crops. The cultivated soils of the Yaroslavl region are sod, strongly, moderately and weakly podzolic soils developed on deposit and boulder clay loams as well as on sandstones (Table 5).

Table 6 shows the average Ti content of the cultivated soils on various parent materials in the region (computed from 18 profiles).

As Tables 5 and 6 show, the Ti content in the cultivated horizon increases slightly in cultivated sod-podzolic soils developed on clay loam deposits and planted to crops (profiles 46, 57, 61, 129 and others), decreasing somewhat in the podzolized horizon and gradually increasing with depth reaching a maximum in the parent material. The increase in higher Ti content in the cultivated layer is probably due to its absorption by field crops and accumulation in that part of the profile following the mineralization of residues and root material. Comparing the profiles of soils under forest vegetation with cultivated soils (starting with the A_1 horizon under forest and the A_p horizon) developed on clay loam deposit one finds that the cultivated soils contain slightly more Ti.

Weakly podzolized cultivated soils developed on fine clay loam deposits are richest in Ti throughout the entire profile owing to the high Ti content in the parent material and the frequent presence of gleyed soil in the lower horizons (profiles 55, 46 and others).

The Ti content in the cultivated soils on boulder clay loam (profiles 118, 133, 17 and others) is slightly lower than in the soils on clay loam deposits, owing to the coarser texture of the former and the lower Ti content in the parent material. The Ti distribution in the genetic horizons is similar to that in soils on less homogeneous parent materials.

Cultivated soils on sandstones (profiles 4, 8, 16 and others) contain still less Ti than those on boulder clay loam but almost twice as much as there is in sod-podzolic soils developed under forest on sandstone. Moreover, Ti accumulation is observed throughout the profile of cultivated sandy soils and particularly in horizon B (roughly one-and-a-half times, on the average, the amount in the parent material of the three horizons underneath).

Compared with the mean Ti content throughout the profile of soils under forest, cultivated soils are richer in Ti. This is apparently due to a gradual decreasing transfer and migration of nutrients (including Ti) when forest sod-podzolic soils are cultivated (plowing, application of fertilizers, sowing of field crops and so forth) and possibly also to some fixation of the Ti in the form of organo-mineral complex compounds.

Titanium Content in Soils Under Meadow Vegetation

As there are extensive meadow lands in the Yaroslavl region (up to 20% of the total area), the Ti content in soil profiles in dry valley, lowland and flood-plain meadows was determined for the sake of comparison.

Dry valley meadows form on the higher parts of the relief after reduction of forest; grass in such meadows are stunted and yields low. Lowland plains are usually found in depressions and low lying areas among the flooded places with groundwaters more or less near the surface. Such lands are richer in vegetation, which consists of various small grasses; characteristic hairgrass meadows often form. Flood-plain valley meadows are usually associated with river valleys and distinguished by a great variety of vegetation.

Table 5

Ti content in sod-podzolic arable soils, %

Sample No.	Horizon	Depth, cm	Ti
Profile 61. Sod-podzolic on fine clay loam deposit over calcareous clay loam. Cultivated.			
1	A_p	0—8	0,318
2	A_p	21—31	0,282
3	B	60—70	0,294
4	C	150—160	0,282
5	D	410—430	0,252
Profile 129. Sod-moderately podzolic on fine clay loam deposit. Cultivated to flax.			
6	A_p	0—10	0,267
7	A_2	22—27	0,260
8	B	40—50	0,298
9	BC	100—110	0,316
10	C	200—220	0,397
11	C	240—260	0,324
Profile 46. Sod-moderately podzolic on medium clay loam deposit with indications of gleying. Spring wheat.			
12	A_p	0—10	0,315
13	A_2	21—31	0,315
14	B	50—60	0,349
15	C	150—160	0,349
Profile 55. Sod-weakly podzolic on fine clay loam deposit over boulder clay loam. Clover + timothy.			
16	A_p	0—10	0,432
17	A_2B_1	21—27	0,408
18	B_2	50—60	0,494
19	BC	100—110	0,420
20	Cgl	170—175	0,432
21	Cgl	230—250	0,462
22	C	300—320	0,594
23	D	430—450	0,336
Profile 57. Eroded sod-podzolic on fine clay loam deposit over calcareous boulder clay loam. Clover + timothy.			
24	A_p	0—10	0,240
25	B_1	25—35	0,192
26	B_2	60—70	0,276
27	C	165—175	0,282
28	D	385—390	0,204
Profile 118. Sod-moderately podzolic on boulder clay loam. Seeded to oats.			
29	A_p	0—10	0,270
30	A_2B	35—40	0,293
31	B	50—60	0,360
32	C	135—140	0,322
Profile 133. Sod-strongly podzolic on boulder clay loam. Clover + timothy.			
33	A_p	2—10	0,295
34	A_2	27—37	0,270
35	B	55—65	0,270
36	C	150—155	0,315
Profile 17. Sod-moderately podzolic sandy-clay loam on coarse boulder clay loam. Clover + timothy.			
37	A_p	0—10	0,337
38	A_2	21—30	0,259
39	B	45—55	0,360
40	BC	90—100	0,360
Profile 4. Sandy loam, sod-strongly podzolic on sand over boulder clay loam.			
41	A_p	0—10	0,308
42	C	88—98	0,209
43	D	138—143	0,360
Profile 8. Sandy loam, sod-weakly podzolic on sand over moraine.			
44	A_p	0—10	0,259
45	D	155—160	0,337
Profile 16. Sod-weakly podzolic on sand over moraine.			
46	A_p	0—10	0,293
47	C	70—80	0,230
48	D	90—95	0,360

Note: comma represents decimal point.

The Ti content in sod-podzolic soils under meadow vegetation (dry valleys, lowlands and floodplain meadows) is shown in Table 7.

Since there is little variation in the Ti content of these soils owing to differences in the kind of parent material (apart from profile 47), Table 8 shows the mean Ti content in meadow soils without a breakdown by types of parent material. As can be seen from Tables 7 and 8 the same tendency occurs in the distribution of Ti in sod-podzolic soils under forest pastures and meadows (profiles 59 and 47) as in soils covered by forest vegetation: the Ti content increases down to the parent material. The presence of meadow grass, however, is felt in a certain increase in the Ti content in the topsoil as compared with the podzolized A_2 horizon, where its transport is more marked. Profile 47 is almost twice as rich in Ti as profile

Table 6

Average Ti content in sod-podzolic cultivated soils, %

Horizon	Clay loam deposit		Boulder clay loam		Sandstone	
	Ti	Range	Ti	Range	Ti	Range
Ap	0,306	0,240—0,435	0,279	0,270—0,300	0,260	0,200—0,337
A_2	0,283	0,192—0,410	0,272	0,262—0,295	0,233	0,210—0,260
B	0,332	0,275—0,495	0,298	0,264—0,360	0,280	0,240—0,360
C	0,343	0,224—0,594	0,302	0,204—0,360	0,185	0,140- 0,230

Note: Comma represents decimal point.

59, owing to the higher Ti content in the parent material (up to 0.5% Ti).

In sod-moderately podzolic soils under dry valley meadows (profiles 37, 19, 44, 45 and others), there is a certain increase in the Ti content in horizon A_1 even in comparison with the parent material (profiles 19, 44 and others); this is probably due to the accumulation of Ti by meadow vegetation; Ti accumulation is observed in the illuvial horizon (profiles 37, 19 and others) and especially in the gleyed part of the profile (profile 45 and others). The whole upper part of profile 19 contains considerably more Ti than the parent material, because of the formation of soil in this profile on sandy, boulder clay loam. There are fewer colloidal particles to bind the Ti here and therefore the plants more readily adsorb it and consolidate it in the upper part of the profile.

On the average (12 profiles), sod-podzolic soils under dry valley meadows contain less Ti than forest and cultivated soils. This may possibly be because the enrichment of soils under the dry valley meadows with ash elements (including Ti) is due only to those elements which remain in the soils with the roots, whereas a considerable portion of these is annually removed during cutting and pasturing. Since the vegetation in dry valleys is usually sparse, stunted and low yields, however, the accumulation of Ti in these soils may of course be very slight.

In the sod-podzolic, often gleyey soils of lowland meadows (profiles 25, 48, 43, 50, 41 and others) formed on deposit and boulder clay loams and gleyed clay, Ti accumulation is more marked throughout the entire profile. Here again, there is a gradual increase in the Ti content down the profile, with a maximum in the parent material. In some profiles, however, (43, 50, 41, 33 and others) there is an accumulation of Ti in the illuvial horizon (in soils formed on boulder clay loam, where migration of Ti down the profile is easier). The increase in the Ti content in the gleyed horizons should also be noted (profiles 33, 34, 52).

On the average, the Ti content in soils under lowland meadows is 1.2 times higher than in soils under dry valley meadows, probably because of the richer vegetation of the former, which forms a compact turf, and also because of the frequent occurrence of gleyization of these soils and the higher level of the groundwaters in such profiles.

In the sandy-loam and sandy stratified soils of floodplain meadows (profiles 28, 40, 49 and others), the distribution of Ti down the profile is uneven, obviously because of the annual depositions by river alluvia. The Ti content in the profile of sandy floodplain soils is very low in comparison with soils under dry valley and lowland meadows.

Discussion

As we noted previously, considerable migration of many elements and nutrients, some of which are gradually transferred from the upper horizons to the lower, by the downward and lateral flow of the soil waters, some of which accumulate in the illuvial horizon and some of which are transferred into horizons A_0 and A_p by the vegetation, occurs during the formation process of sod-podzolic soils under forest canopy (with herbaceous cover).

From the data we have given (Tables 3 and 4), it would appear that the soil compounds of Ti undergo similar transformation. Vernadskiy believed that Ti must accumulate in soils since it could not be removed from them during weathering owing to the low mobility and low solubility of its compound in water and soil solutions. The research of Polynov and Tumilovich (7) and of Sedletskiy (9) and others, however, as well as the results of our own investigations given previously, indicate that Ti soil compounds do migrate in the process of podzol formation. The ways in which it moves in soils have not yet been studied. It is known that primary Ti compounds in the weathering crust decompose very slowly, forming a series of secondary titaniferous minerals which go to the making up of colloidally-dispersed compounds. The secondary Ti compounds accumulated primarily in fine soil fractions acquire the capacity to migrate under the influence of available humic acids formed during the decomposition of forest litter. Polynov (7) believes that the decrease in Ti content in the upper part of the profile of podzolic soils is a result of its poor absorption by organisms.

Some foreign investigators (14, 12) and a number of Soviet scientists have established that Ti is widely distributed in plant and animal tissues, again as a result of the migration capacity of Ti soil compounds which can yield compounds in the form of gels and gradually turn into sols and solutions. After the mineralization of forest litter-fall and herbaceous

Table 7

Ti content in soils under meadow vegetation, %

Sample No.	Horizon	Depth, cm	Ti
Profile 59. Sod-weakly podzolic on fine clay loam deposit over boulder clay loam. Forest pasture.			
1	A_0	0—3	0,228
2	A_2	3—12	0,168
3	B_2	30—40	0,246
4	B_3	50—60	0,264
5	BC	80—90	0,228
6	C	150—155	0,246
7	D	450—455	0,196
Profile 47. Sod-strongly podzolic on clay loam medium deposit. Dry valley forest meadow.			
8	A_0	0—9	0,490
9	A_2	12—22	0,392
10	B	40—50	0,442
11	BC	70—79	0,481
12	C	130—135	0,508
Profile 37. Sod-moderately podzolic on clay loam deposit over moraine. Dry valley meadow.			
13	A_1	0—10	0,206
14	B	66—77	0,270
15	D	145—150	0,248
Profile 19. Sod-moderately podzolic on sandy boulder clay loam. Dry valley various grass meadow.			
16	A_1	0—10	0,187
17	A_1A_2	17—26	0,248
18	A_2	34—43	0,238
19	B	56—64	0,281
20	C	120—125	0,153
Profile 44. Sod-moderately podzolic on coarse boulder clay loam. Dry valley meadow (various grasses).			
21	A_1	0—10	0,210
22	A_2B_1	25—35	0,164
23	B	45—59	0,187
24	BC	95—100	0,206
Profile 45. Peaty-humic-gleyed on boulder clay loam. Swamp patella on dry valley meadow (sedge, green mosses)			
25	A_{peat}	0—10	0,173
26	A_1	10—20	0,184
27	B	30—40	0,289
28	C	100—105	0,221
Profile 25. Sod-gley podzolic on clay loam deposit. Lowland meadow (cereal and other grasses).			
29	A_1	0—10	0,330
30	A_2	12—22	0,348
31	B	47—57	0,356
32	BC	110—115	0,372
33	C	130—150	0,378
Profile 48. Sod-podzolic weakly-gleyed on blanket loam. Lowland meadow (herbaceous and grasses).			
34	A_1	0—10	0,248
35	A_2	17—25	0,259
36	B_2	55—65	0,281
37	C	145—150	0,346
Profile 43. Sod-gley with slight signs of podzolization on calcareous boulder coarse clay loam. Lowland meadow.			
38	A_1	0—10	0,270
39	A_2B_1	30—40	0,281
40	B_2	60—70	0,346
41	C	135—140	0,294
Profile 50. Sod-gleyed podzolized on calcareous boulder coarse clay loam. Lowland meadow (rush, hairgrass).			
42	A_1	2—10	0,153
43	A_2	22—30	0,216
44	B	45—55	0,238
45	C	115—120	0,206
Profile 41. Sod-gleyed podzolized on clay loam deposit over boulder clay loam. Lowland meadow.			
46	A_1	0—10	0,216
47	A_2	27—37	0,248
48	A_2B	50—58	0,322
49	B	73—82	0,366
50	C	125—130	0,322
Profile 33. Sod-medium podzolic gleyed on clay loam over gleyed clay. Lowland meadow.			
51	A_1	0—10	0,299
52	Bgl	56—65	0,349
53	C	135—140	0,295
Profile 34. Sod-gleyed weakly-turfed on clay loam over gleyed clay. Lowland meadow.			
54	A_1	2—10	0,281
55	BC	90—95	0,298
Profile 52. Weakly-sod-podzolic gleyed on strongly gleyed clay. Lowland meadow (hairgrass).			
56	A_1	2—6	0,206
57	A_2	6—11	0,238
58	B	30—40	0,281
59	C	105—110	0,324
Profile 28. Sod-sandy loam floodplain. Flooded meadow.			
60	A	0—10	0,206
61	Sand	155—160	0,218

Note: Comma represents decimal point.

Table 7 continued

Sample No.	Horizon	Depth, cm	Ti	Sample No.	Horizon	Depth, cm	Ti
Profile 40. Sandy-loam sand alluvial stratified floodplain. Floodplain meadow (grasses).				Profile 49. Alluvial swamp. Flooded floodplain meadow.			
62	A	0—9	0,197	64	A	0—10	0,164
63	—	145—150	0,207	65	Sand	65—70	0,210

Note: Comma represents decimal point.

Table 8

Average Ti content in soils under meadow vegetation, %

Horizons	Dry valley meadows		Lowland meadows		River meadows	
	Ti	Range	Ti	Range	Ti	Range
A_1	0,218	0,173–0,290	0,249	0,153—0,330	0,189	0,160—0,260
A_2	0,190	0,164—0,240	0,265	0,216—0,350	—	—
B	0,249	0,187—0,282	0,307	0,238—0,356	—	—
C	0,280	0,153—0,368	0,320	0,206—0,384	0,202	0,185—0,218

Note: Comma represents decimal point.

residues, the released Ti can accumulate in the upper part of the profile in the form of organic and mineral complex compounds which are more mobile than mineral Ti.

Until recently, very little attention was paid to discovering the physiological role of Ti in the life of plant and animal organisms. Its presence in many animal and human organs as well as in vegetation indicates that it does play some part in the process of organic compound synthesis although we have seen no information on this subject in the literature.

The increase in Ti content in the profile of sod-podzolic cultivated soils as well as in soils under lowland meadows indicates that field crops and various grasses in lowland meadows store this element and that when such vegetation is mineralized, the upper part of the profile of these soils is gradually enriched with Ti in comparison with forest soils, where loss mainly outweighs accumulation.

Conclusions

1. Cultivated sod-podzolic soils contain more Ti than soils developed under forest vegetation. Sod-podzolic soils under meadow contain various quantities of Ti: soils under lowland meadows are richest, those under stratified floodland have the least amount of Ti.

2. No appreciable differences are observed in the Ti distribution along the genetic horizon of sod-podzolic soils formed on deposits and boulder clay loams and occupied by forest trees or field crops. The general trend in the distribution of Ti along the profile of these soils is as follows: gradual increase from the A_0 horizon (under forest) and the A_p horizon, towards the lower part of the profile, reaching a maximum in the parent material. In cultivated soils, there is often some decrease of the Ti content in the podzolized horizon, whereas in soils under forest vegetation there is sometimes a certain increase in the quantity of Ti in the illuvial horizon in comparison with the parent material. All this indicates that Ti soil compounds migrate in the process of podzol formation.

3. In sodpodzolic cultivated and forest soils developed on sandy parent material, there is a relative increase in the Ti content in horizons A_p, A_1, A_2 and especially B, in comparison with the parent material, probably as a result of the accumulating influence of the vegetation and the greater readiness of the Ti compounds to migrate along the profile of sandy soils.

4. In the gleyed horizon of the soil and parent materials, there is a marked increase in the content in Ti, which is brought in from surrounding areas with ground water near the surface or surface waters.

5. Fine-textured soils, containing a considerable quantity of colloidal substances, are richer in Ti than coarse-textured soils (sand and sandy loam).

6. The Ti content in different types of forest litter (spruce forests, mixed spruce, larch and pine) does not depend much on the type of forest but mainly on the texture of the soil and parent material; the Ti content is appreciably lower in

coarse- than in fine-textured parent materials.

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MICROELEMENT CONTENT IN THE SOILS OF BELORUSSIA

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There is very little information on the microelement content in the soils of the Belorussian SSR. To cover this gap, the Institute of Agriculture of the Belorussian Academy of Agricultural Sciences initiated research into the content and distribution of the total microelement content in the soils of the Republic in 1955.[1]

Objectives of Research

Soil-forming rocks. Samples of moraine clay loams were taken in the central and southern regions of Belorussia at depths of 1.2-8.5 m. In all cases, the moraines were carbonates and differed comparatively little in texture and

Table 1

Microelement content in moraine clay loams

Locality	Depth, m	pH in water	Total microelement content, mg/kg of par. material				
			Zn	Cu	Ni	Co	Mo
Mstislavl district	1,2—1,3	8,31	18,0	5,9	6,0	2,1	1,3
Lebed' valley, Grodnensk. Oblast'	1,2	7,60	8,0	5,8	3,5	4,4	2,0
Derzhinskiy dist.	4,2	7,47	22,0	7,0	4,4	1,2	3,5
Mozyr' district	8,0—8,5	7,0	22,8	6,0	6,0	4,8	2,3

Note: Comma represents decimal point.

Table 2

Microelement content in loess-like clay loams

Locality	Depth, m	pH in water	Total microelement content, mg/kg of par. material				
			Ni	Zn	Cu	Co	Mo
Mstislavl district	2,9	7,9	30,0	10,1	8,8	8,5	4,3
Mstislavl district	5,5	7,67	30,0	5,0	5,2	8,2	4,3
Novogrudok dist.	1,8—2,0	7,71	30,0	30,0	5,3	3,6	4,8
Novogrudok dist.	3,8—3,9	7,80	25,0	20,0	4,5	1,7	1,8
Minsk brick factory	1,7—2,4	6,90	35,0	45,0	5,6	3,4	4,7
Minsk brick fact.	5,4	7,78	35,0	30,0	5,0	1,3	4,9

Note: Comma represents decimal point.

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[1] In addition to the authors of the paper, the followin took part in collecting and describing the soil samples: T. A. Romanova and A. Ye. Ryazanov. Parent materials, moraine, and loess-like clay loams were provided by M. M. Tsapenko; samples of the peat-bog and swamp soils of the Sloust River basin were collected by T. F. Golub. Yu. I. Gavrilenko and Ye. I. Lazarchik took part in the analytical work.

color. Samples of loess-like clay loams were taken in regions where they are commonest at depths varying from 1.7-5.5 m (to a depth of 1.7-2.4 m in the case of the Minsk brick factory quarry); the carbonate samples have a coarse clay loam texture and the typical loess-like clay loam texture and color. The loess-like clay loams from the Novogrudok district (from a depth of 3.8-3.9 m) and from the Minsk brick factory are gleyed, the latter being carbonate-free. The results of parent material analyses are shown in Tables 1 and 2.

Sod-podzolic soils on moraines and lacustrine clay loams and clays, which are characteristic of the northern districts of Belorussia, are represented by profiles 1, 2, 3 and 4.

Profile 1. Kholopenichi region, on flat top of moraine hillock, spruce mixed with grass-moss cover.

Profile 2. Neighboring moraine hillock, cultivated. The soils in profile 1 and 2 are moderately podzolic clay loams with a well-expressed podzolic horizon, developed on medium and coarse moraine clay loams passing to clay (profile 1) or fine clay loam (profile 2) with depth. Effervesces at a depth of 100-110 cm. Humus content in horizon A_1: under forest —5.9%, cultivated —1.9%. (Table 3).

Profile 3. In the Sharkovshchin district on slight local flat watershed, pine stand with small berry patches and moss-grass cover.

Profile 4. Situated not far from profile 3 on very gentle cultivated slopes. The soils in profiles 3 and 4 are moderately podzolic, superficially gleyed, fine clay loams, developed on fine silty clay loams over lacustrine (layer) clay. Effervesces at a depth of about 70 cm. Humus content in A_1 horizon: under forest—10%, in cultivation—2%. (Table 4).

The following profiles characterize the soils in the central regions of Belorussia.

Profile 5. Cultivation in the upper third of slight slope of small rise on loess plateau in the vicinity of Gorki. Dark colored, podzolized, coarse clay loams with pronounced podzolic horizon on thick loess clay loam; does not effervesce above a depth of 2.5 m. Humus content: A_1 —1.7%, A_p —1.5% (Table 5).

Profile 6. Orsha district, Ust'ye experimental station, from gentle slope on border of cut-over spruce forest with thick spruce undergrowth and grass cover.

Profile 7. Cultivated, not far from profile 6. Soils in both profiles are strongly podzolic, coarse clay loam on silty clay loams over moraine clay loam, which gives way to sand at a depth of 1.5 m in the forest. Humus content in horizon A_1 about 2% (Table 5).

Profile 8. In the vicinity, on flat local watershed in pine-mountain cranberry forest with grass-moss cover. The soil is weakly podzolic, cohering sand on cohering fluvioglacial sand. Does not effervesce above a depth of 230 cm. Humus content in A_0 horizon 7% (Table 6).

Profiles 9 and 10 are in the Poles'ye, Vasilevichi district, Poles'ye experimental station.

Profile 9. Flat local watershed in pine forest with heather with occasional grass cover on weakly podzolic, sandy soil gleyed underneath, developed on fine-grained old alluvial sand.

Profile 10. Gentle slope near profile 9, cultivated. The soil is deeply podzolic, with contact gleyzation, cohering sands on cohering fine-grained sand over moraine clay loam at a depth of about 1 m. Dark-bluish-whitish reduced materials and large rusty ocher spots are very marked in the soil profile at a depth of 65-75 cm. Humus content in A_1 horizon: under forest—1.3%. No effervescence detected within the limits of the soil profile (Table 6).

Profile 11. Sod-podzolic-gleyed soil in low local watershed in the Tolochin district in cut-over spruce forest with matgrass cover. Soil appreciably podzolized, clay loam, developed on coarse silty clay loam. Effervesces at a depth of 95 cm. Humus content in horizon A_1 —3% (Table 7).

Profile 12. Not far from profile 11 in flat continuous hollow, sedge-grass, cut for hay. Sod-gleyed clay loam developed on coarse silty clay loam. Effervesces from a depth of 60 cm. At approximately this depth, ground waters are found. Humus content in A_0 horizon — 10.2%; in A horizon — 6.3% (Table 7).

Profile 13. Sod-gleyed floodplain soils from experimental and productive area in floodplain of the Sloust River in the Minsk district. The soil is clay loam, developed on a thin silty clay loam over gravelly, water-bearing sand at a depth of 60 cm (Table 7).

Profile 14. Peaty-humic-gley soil not far from profile 13. The peaty sedge-alder layer is 25 cm thick; under this is a humic clay loam horizon (down to 30 cm) and below this a gleyed silty clay loam, giving way to water-bearing sand at a depth of 95 cm (Table 8).

Profile 15. Humic-carbonate gleyed sandy loam on slight rise in the middle of low bog in the Vasilevichi district in sparse oak-ash forest with herbaceous vegetation. The soil is characterized by a thick (32 cm) humus horizon, under which is a half-meter stratum of sandy loam marl containing large ocher spots of ferric hydroxide a depth of 90-100 cm. Fine-grained water-bearing sand is found lower down. Soil and ground waters are at a depth of 10 cm. The soil effervesces at the surface (Table 8).

Profile 16. Peat-bog soil from lowland bog in the experimental and productive part of the Sloust River floodplain, Minsk district. Reed-alder peat, 35%-40% decayed. Thickness—135 cm. Ash content—about 10% (Table 8).

The following methods were used: particle-size analysis—pipette method; pH—electrometrically determined; humus—Tyurin method; bulk density—cutting ring method; degree of bas

Table 3

Microelement content in sod-podzolic soils on moraine clay loams

Profile No.	Horizon	Depth, cm	Particle diameter, %			Bulk density g/cm³	pH		Degree of saturation with bases	Total microelement content, mg/kg of soil						
			0,05–0,01 mm	<0,01 mm	<0,001 mm		Water	Salt		Cu	Ni	Zn	Co	B	J	Mo
1	A_1	2—10	27,0	36,0	20,0	1,36	5,7	5,0	61	11,6	7,5	5,4	1,60	2,5	2,3	2,3
	A_2	12—20	40,0	32,4	15,6	1,66	5,98	4,3	20	12,7	11,2	5,5	4,13	Not det'd.		4,3
	B_2	45—55	19,1	55,6	39,9	1,78	6,29	5,3	88	17,7	19,0	10,0	6,7	"		4,85
	B_3	110—112	19,2	60,3	39,8	—	6,64	6,9	100	17,7	—	12,0	10,0	"		—
2	A_1	2—10	15,6	21,1	13,7	1,51	6,73	5,2	46	11,6	5,6	2,15	0,63	2,8	2,3	2,2
	A_2	25—35	11,8	16,2	9,4	1,72	6,48	5,1	54	11,6	6,1	2,9	0,84	Not det'd.		2,2
	B_1	60—70	17,6	44,6	32,8	1,75	6,48	5,0	87	18,3	12,0	3,8	0,42	"		2,3
	B_3	140—150	30,4	44,4	31,5	—	6,83	6,8	100	22,0	12,0	13,0	0,80	"		2,3

Note: Comma represents decimal point.

Table 4

Microelement content in sod-podzolic soils on lacustrine clays

Profile No.	Horizon	Depth, cm	Particle diameter, %			Bulk density g/cm³	pH		Degree of saturation with bases	Total microelement content, mg/kg of soil						
			0,05–0,01 mm	<0,01 mm	<0,001 mm		Water	Salt		Cu	Zn	Ni	Co	B	J	Mo
3	A_1	5—10	42,8	46,9	25,3	0,82	4,82	4,3	38	18,8	15,0	7,9	1,8	4,3	2,1	1,4
	A_2	10—15	47,2	40,1	20,4	1,63	5,25	4,4	38	15,0	10,7	8,4	5,2	Not det'd.		1,1
	B_1	25—35	26,6	65,2	44,5	1,40	5,76	4,5	81	24,7	13,0	22,0	7,9	"		1,5
	B_2	70—76		Not det'd.			6,0	6,6	100	27,6	9,6	30,0	9,6	"		1,7
	B_3	115—120	14,3	84,4	48,5	1,42	7,5	7,0	100	28,2	9,4	36,0	13,2	"		1,9
	C	125—135	5,0	94,2	63,5	1,40	7,8	7,1	100	29,3	8,3	34,0	10,2	"		1,9
4	A_0	0—5	49,1	41,3	23,5	Not det'd.	4,9	4,4	44	10,0	10,0	5,3	1,06	"		0,84
	A_1	8—18	43,7	45,9	23,8	1,08	5,3	4,4	41	12,8	13,0	5,3	1,06	3,4	2,3	0,68
	B_1	25—35	22,9	72,9	50,2	1,28	5,3	4,3	63	23,0	9,5	13,0	5,35	Not det'd.		0,21
	B_2	60—70	11,8	86,5	59,0	1,38	6,6	6,9	98	33,0	20,4	32,0	10,2	"		1,1
	B	85—95	8,3	91,7	64,5	Not det'd.	7,5	7,2	100	32,0	15,0	30,0	11,3	"		1,3
	C	115—125	6,8	93,2	68,0	"	7,9	7,2	100	31,0	16,0	30,0	11,3			1,7

Note: Comma represents decimal point.

Table 5

Microelement content in sod-podzolic soils on silty clay loams

Profile No.	Horizon	Depth, cm	Particle diameter, %			Bulk density g/cm³	pH		Degree of saturation with bases	Total microelement content, mg/kg of soil						
			0,05–0,01 mm	<0,01 mm	<0,001 mm		Water	Salt		Cu	Ni	Zn	Co	B	J	Mo
5	$A_п$	0—15	65,5	21,2	7,7	1,29	5,37	4,7	53	18,0	9,9	8,5	2,6	2,5	2,1	2,0
	A_1	25—30	63,6	25,3	6,3	1,45	5,43	4,9	54	16,0	7,1	6,6	0,61	Not det'd.		2,0
	A_2	30—40	65,7	21,1	4,8	1,52	5,62	5,0	66	7,7	3,0	0,84	0,5	"		0,61
	B_1	55—65	59,6	31,7	20,3	1,61	5,65	4,6	75	25,0	12,0	4,0	5,6	"		0,70
	B_2	220—250	64,4	22,8	13,4	Not det'd.	5,69	4,5	89	13,4	6,0	6,3	0,51	"		0,25
6	A_1	3—15	65,3	24,1	10,7	1,23	5,34	4,5	26	18,5	7,1	5,45	4,0	3,4	2,7	1,6
	A_2	20—30	56,9	26,4	9,8	1,30	5,36	4,5	39	17,0	6,0	5,8	1,5	Not det'd.		3,3
	B_1	50—60	61,7	26,7	20,0	1,59	5,44	4,3	66	22,0	11,3	7,3	4,1	"		3,3
	B_2	100—110	52,7	25,0	18,4	Not det'd.	5,70	4,1	72	9,7	10,0	6,1	2,0	"		3,3
7	A_1	0—15	55,5	24,3	10,0	1,36	5,30	4,6	44	16,0	7,1	1,6	3,0	2,0	2,2	1,8
	A_2	15—20	64,6	21,4	8,8	1,51	5,37	4,4	33	22,0	4,5	4,4	3,5	Not det'd.		0,75
	B_1	35—45	59,3	30,7	23,4	1,51	5,37	4,4	59	25,0	11,4	8,0	6,0	"		0,51
	B_2	140—150	7,8	23,1	17,4	1,94	5,37	4,1	58	19,0	9,1	3,6	5,0	"		0,40

Note: Comma represents decimal point.

Table 6

Microelement content in sod-podzolic sandy soils on fluvioglacial and on old alluvial sands

Profile No.	Horizon	Depth, cm	Particle diameter, %			Bulk density g/cm³	pH		Degree of saturation with bases	Total microelement content, mg/kg of soil						
			0,05–0,01 mm	<0,01 mm	<0,001 mm		Water	Salt		Cu	Zn	Ni	Co	B	J	Mo
8	A_1	3—8	7,3	15,0	8,2	1,01	5,04	4,1	23	10,0	7,2	9,6	1,85	1,3	1,6	0,89
	A_2	10—15	3,5	11,0	5,4	1,41	5,62	4,6	11	10,0	9,3	8,1	0,70	Not det'd.		0,65
	B_2	50—60	0,9	5,6	4,8	1,73	5,84	5,0	10	10,9	8,5	5,0	None	"		0,41
	B_4	200—210	2,4	4,3	3,6	Not det'd.	6,02	5,1	59	1,6	5,6	Нет	"	"		0,20
9	A_1	3—62	7,8	9,8	5,8	1,23	5,53	4,7	—	12,9	5,6	6,2	"	3,0	2,1	1,5
	A_2	25–40	6,4	10,3	5,0	1,36	5,91	4,8	—	12,9	5,0	3,1	"	Not det'd.		1,9
	B_1	75—90	5,0	4,9	3,6	1,40	5,89	4,9	38	8,3	6,1	7,5	0,21	"		0,75
	B_2	120—130	20,3	8,0	2,9	Not det'd.	5,88	4,9	30	6,5	4,4	6,2	None	"		0,90
10	A_1	2—18	10,3	10,2	6,1	1,32	5,53	4,7	—	13,6	6,6	7,3	0,3	3,0	2,0	1,2
	A_2	30—40	11,6	9,7	4,2	1,64	5,67	5,1	—	9,1	4,9	7,5	0,3	Not det'd.		0,85
	B_1	65—75	6,2	6,0	4,0	1,50	5,86	5,0	8	7,2	7,1	8,3	0,67	"		0,73
	B_2	75—90	26,5	9,2	6,7	1,55	5,84	5,2	47	5,7	7,5	4,4	0,9	"		0,75
	B_3	90—95	14,6	31,5	24,5	1,58	5,89	4,3	53	13,4	9,0	9,1	1,2	"		0,51

Note: Comma represents decimal point.

Table 7

Microelement content in sod-podzolic bog and sod-bog soils on silty clay loams

Profile No.	Horizon	Depth, cm	Particle diameter, %			Bulk density g/cm³	pH		Degree of saturation with bases	Total microelement content, mg/kg of soil						
			0,05–0,01 mm	<0,01 mm	<0,001 mm		Water	Salt		Cu	Zn	Ni	Co	B	J	Mo
11	A_1	2—10	48	29,5	12,4	1,31	5,96	4,4	37	20,1	14,0	6,1	4,51	3,6	2,1	0,50
	A_2	15—20	50	19,2	8,2	1,52	5,96	4,5	54	14,4	8,4	4,0	2,5	Not det'd.		0,76
	B_1	35—45	52	25,7	17,6	1,54	6,01	4,8	81	20,3	12,0	14,0	4,6	"		0,52
	B_2	65–75	52	24,3	15,7	Not det'd.	6,28	5,0	90	22,0	14,0	12,0	3,0	"		0,45
	C	100—110	52	20,8	13,3	1,67	6,83	6,4	100	17,9	8,4	11,0	1,0	"		0,45
12	A_1	2—15	52,0	34,0	19,5	0,82	5,89	5,8	88	17,5	7,4	9,2	3,0	2,6	1,2	0,85
	B_1	30—40	52,0	23,2	15,8	1,71	6,45	6,0	97	30,3	5,3	14,0	2,0	Not det'd.		1,30
	B_2	60—70	54,0	35,8	20,0	1,72	7,33	7,0	100	40,1	11,7	11,0	2,0	"		1,0
	B_4	90—100	54,0	31,8	20,2	1,84	7,70	7,4	100	39,0	4,7	12,0	1,5	"		0,92
13	A_1	3—12	Not det'd.			1,479	6,27	Not det'd.		29,6	14,0	5,2	None	Not	3,0	0,51
	B_1	45—60	"			1,668	7,12	"		31,0	13,0	3,1	"	det'd.	1,4	0,75
	C	140—150	"			1,74	6,70	"		22,4	9,0	3,5	"	Not det'd.		1,60

Table 8

Microelement content in humus-carbonate and peat bog soils

Profile No.	Horizon	Depth, cm	pH in water	Total microelement content, mg/kg of soil						
				Cu	Zn	Ni	Co	B	J	Mo
14	A	2—20	5,52	41,0	11,9	11,4	1,1	Not det'd.	1,8	0,5
	B_1	50—60	6'87	19,0	11,3	9,5	1,1	"	Not det'd.	0,69
	C	100—110	7,25	15,4	8,4	8,7	2,4	"	"	0,98
15	A_1	1—20	7,65	16,0	6,0	11,0	None	"	3.6	1,36
	A_2	20—30	7,75	14,7	7,5	10,5	"	"	Not det'd.	1,54
	B_1	40—50	8,44	13,4	6,1	6,6	"	"	"	1,45
	B_1	65—80	7,97	23,0	6,1	4,4	"	"	"	1,28
	B_2	90—100	7,80	17,3	5,9	4,4	"	"	"	1,02
	C	110—130	7,45	10,9	5,4	3,3	"	"	"	0,91
16	A	2—20	6,47	21,0	3,8	14,0	"	"	"	1.0
	T_3	60—70	6,30	11,0	3,8	8,7	"	"	"	Not det'd.
	T_4	120—130	6,60	7,0	10,0	11,0	"	"	"	"

Note: Comma represents decimal point.

saturation was calculated by finding the sum of the adsorbed bases by Kappen's method.

Except for boron and iodine, the content in all microelements was determined by colorimetric methods by means of a Pulfrich photometer.

Copper was measured colorimetrically in its diethyldithiocarbonate complex in the chloroform layer with a green light filter.

Zinc was determined in its diphenylthiocarbasol combination in the carbon tetrachloride layer with a green light filter.

Nickel was determined in a dimethylglioxine combination of trivalent nickel in aqueous solution with a blue-green light filter.

Cobalt was determined in the form of a complex with nitroso-R-salt solution with a green light filter.

Molybdenum was determined in the thiocyanate complex of pentavalent molybdenum in the isoamyl alcohol layer with a blue light filter.

We found the microelement content by colorimetric readings, using the calibration curves constructed for the accurately-known quantities of microelements in their standard solutions. Boron and iodine were determined by known microvolumetric methods. The sources for the methods used are indicated in the list of references.

The data given in Tables 1-8 show that the loess-like clay loam parent materials are richer, in total content, in the majority of the microelements, especially nickel, than the moraine parent materials and that the sod-podzolic soils developed on loess-like clay loams are correspondingly richer in microelements than those on moraine clay loams. The difference between the loess-like and moraine clay loam parent materials in regard to microelement content is obviously due to the difference in the conditions under which these parent materials are differentiated from their parent material and the difference in their subsequent enrichment in microelements from ground waters and the atmosphere.

The zinc content is higher in the loess-like and the moraine clay loam parent materials than in the soils, whereas the copper and cobalt content is lower. In the parent materials, the zinc content is usually 2-3 times higher than the copper content. Conversely, there is as a rule more copper than zinc in the soils, especially in the upper horizons. The obvious reason why the copper and cobalt is higher in the soils than in the parent materials is that in the process of biological migration of the microelements, copper and cobalt accumulate and are stored in the soil organic matter, while microelements are applied into the soil along with fertilizers and as part of the dust and ash falling out of the atmosphere. The lower zinc content in the soils in comparison with the zinc content in parent materials is apparently due to the mobility of the zinc and its considerable loss from the soils. The loess-like parent materials contain more, and the moraine parent materials less nickel than the soils.

All the soils under consideration have by and large the same order of microelements in series where they are arranged in descending order according to their content in these soils. In this respect, copper heads the list. There is some variation in the elements which occupy the second and third places in this series: in some cases, nickel comes second and zinc third; in others, zinc comes second and nickel third.

By arranging the microelements in a series, we are able to distinguish groups of microelements which occupy respectively high (Cu, Ni, Zn) and low (Co, B, I, Mo) places in the list.

Many soils are similar as regards microelement distribution in their genetic horizons. In sod-podzolic clay loams, (profiles 1, 2 and 3, 4) the content in all microelements (except in certain cases zinc) gradually increases from the upper to the lower horizons. This is apparently due to an increase in the content of particles smaller than 0.001 mm in diameter and is a reflection of weathering, leached and illuvial processes. In sod-podzolic soils developed on coarse-textured parent material (profiles 8, 9, 10), the content of the same microelements gradually decreases down the profile owing to the decrease of the clay fraction in this direction.

In swamped and bog soils (profiles 13 and 15), we find increased concentrations of the majority of microelements in the upper horizons, apparently due to biological accumulation. In a number of soils formed on silty clay loams, the molybdenum concentration decreases uniformly from top to bottom while the concentration of copper, nickel and cobalt in the humus horizon is higher than in podzolic soils but lower than in the illuvial soils (profiles 5, 6, 7).

Of all the soils investigated, the sod-podzolic gleyed, sod-gleyed and peaty-humic soils have the highest content in copper, zinc, nickel and certain other microelements (profiles 3-4, 11-12, 13 and 14) while the lowest content in these elements is in sod-podzolic soils on sandy loams and in deep fluvioglacial sands (profiles 8, 9, 10).

The foregoing data indicate that the character of the parent material, the chemical composition of the salts, ground waters and atmospheric precipitation and other factors, including man's agricultural activity, influence the distribution of microelements in soils.

The following are the distribution characteristics of particular microelements in the soils under consideration.

Copper is found in greatest concentrations in peaty-humic, sod-gley, podzolic gleyed and sod-podzolic fine clay loams (profiles 14, 13, 12, 3 and 4) where its content in the A, A_1 and B horizons reaches 30-40 mg/kg. In all soils with developed podzolic and illuvial horizons, an appreciable accumulation of copper is clearly seen in the illuvial horizons. This is particularly noticeable in the illuvial horizon of coarse clay loams on loess-like clay loam (profiles 5, 6 and 7). In the upper horizons of these soils, the copper content is 18-16 mg/kg while in the B_1 horizon it is 22-25 mg/kg.

In moderately podzolic soils on moraine clay loam the illuvial horizons are also richer in copper (17.7-22 mg/kg against 11.6-12.6 mg/kg in horizons A_1 and A_2, profiles 1-2 and 3-4). The humus horizon of these soils is poorer in copper than the illuvial horizons by a factor of 1.5-2.0. Sandy soils contain less copper, especially in the lower horizons.

The data we have given show that copper is genetically associated with the clay minerals in soils and accumulates in horizons rich in the clay fraction.

The highest concentrations of nickel are in the loess-like parent materials. In the lower horizons of fine clay loam on lacustrine clay (profiles 3-4) and in the illuvial horizon of coarse clay loam on loess-like clay loam (profile 5) the nickel content reaches 30 mg/kg. In sod-podzolic gleyed coarse sandy loams on moraine and moderately podzolic clay loam on moraine (profiles 11-12, 6-7 and 1-2) the lower horizons are richer in nickel, its concentration reaching 12-19 mg/kg. The upper horizons of all the soils studied, apart from the peaty-humus and humus-carbonate, are poor in nickel. This indicates that nickel, like iron, has considerable mobility in sod-podzolic soils.

Zinc, like nickel, is found in greatest quantities in loess-like parent materials, where its content varies between 5 and 45 mg/kg. The zinc content in the soils decreases, but the maximum zinc concentrations are all in the upper and illuvial horizons of the soils: fine clay loam on clay layer (profiles 3, 4) podzolic gleyed and sod gleyed (profiles 11, 12) peaty humus and peat bog soils (profiles 14, 16), where the quantity varies from 14-20 mg/kg. In most of the other soils, the zinc content varies between 2 and 9 mg/kg. In some cases, the zinc content in the soils is higher than the nickel content, in others lower. In all the soil samples analyzed, as distinct from the parent materials, the quantity of zinc was either equal to the copper content or several times less than it.

The highest cobalt concentrations were in the lower horizons of fine clay loam on lacustrine clay and moderately podzolic soil on moraine clay loam. The maximum cobalt concentration in the first soil was 13 mg/kg and in the second soil, 10 mg/kg. Some accumulation of cobalt was observed in the illuvial horizons of coarse clay loam on loess-like clay loam, strongly podzolic coarse clay loam on moraine clay loam and gleyed soil on silty clam loam (profiles 5, 6, 7, 11-12), where the content varied from 2-5 mg/kg. Sod-podzolic sandy soils (profiles 8, 9, 10) were poorest in cobalt. None at all was detec-ed in sod-gleyed, peat bog and humus carbonate gleyed sandy loam soils (profiles 13, 15, 16). The cobalt content in swamped soils with waters was negligible, apparently owing to the extremely slight cobalt content in the soil and ground waters associated with the low cobalt content in sandstone rocks.

Boron and iodine were determined only in the humus horizons, in quantities varying from 2-4 mg/kg. The highest boron content occurred in he upper horizon of soil formed on clay layer (profile 3) and also in the humus horizon of forest soils (profiles 6, 11). In soils developed on sandy parent material, the boron content is lower.

Molybdenum is contained in loess-like and moraine parent materials in greater concentrations than in soils, the molybdenum concentration in these materials varying between 1.3 and 4.9 mg/kg. The moderately podzolic soil on moraine clay loam (profiles 1-2)is richer in molybdum (2.2-4.8 mg/kg) as is the forest sod-podzolic soil on silty clay loam. Moderately podzolic soils on lacustrine clays and especially the weakly podzolic sandy loams (profiles 3, 8), the sod-podzolic gleyed (profiles 11,12), the sod gley (profile 13), and the peaty humus gley (profile 14) are poor in molybdenum, containing only 0.5-0.89 mg/kg of this element.

Conclusions

1. In regard to total content of the majority of microelements, the loess-like clay loams are richest among the parent materials of Belorussia and are particularly rich in nickel. The moraine clay loams are poorer in microelements. As a result, the sod-podzolic soils formed on loess-like clay loams are richer in microelements than the soils formed on other parent materials.

2. It has been established that the content of Cu, Ni, Zn and Co in the Belorussian sod-podzolic clay loams diminishes in horizons A_1 and especially A_2 and increases in the illuvial horizons (B_1 and B_2). The copper content in the soils is usually several times greater than the zinc content in the same horizons.

3. Sod-podzolic gleyed soils on lacustrine clay, gleyed soils on coarse silty clay loam and peaty humus soils have a distinctly higher content in copper, nickel and zinc. The highest cobalt content was established in the lower horizons of soils formed on lacustrine clays and moraine clay loams as well as in the illuvial horizons of soils on silty clay loams. Sod-podzolic soils on sands, as well as peat bog and humus-carbonate bog soils proved to have the lowest cobalt content.

4. It has been found that the microelements can be arranged in a single list in descending order of importance according to their concentration in each soil, for all the Belorussian soils.

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REVIEWS

SOILS OF BULGARIA

Published by Academy of Sciences, USSR. 1959.

The monograph "Soils of Bulgaria" is a valuable gift from Soviet and Bulgarian soil scientists to Bulgarian scientific circles on the eve of the 15th anniversary of the Bulgarian people's liberation from the bourgeoisie and from fascism. Only the people's power has made possible such fruitful cooperation between Soviet and Bulgarian specialists, a cooperation which is deepening and which is of direct assistance to the building of socialism and to scientific development in the country.

We wish to stress that this is the most important study of the soils of Bulgaria. The work was undertaken by Academician Gerasimov, Academician Antipov-Karatayev of the Tadzhik Academy of Sciences (joint leaders of the Soviet-Bulgarian soil expedition of 1947 and sponsors of the monograph), Academician Tyurin, who supervises the research workers of the Pushkarov Soil Institute of the Ministry of Agriculture and Forestry and the Bulgarian Academy's Soil Institute, and other specialists working in related fields.

The bulk of the work was carried out by the V. V. Dokuchayev Soil Institute of the USSR Academy of Sciences and by the Pushkarov Soil Institute. There are 400 pages of text and tables. The wealth of analytical data on various soil properties is contained in 140 tables and 61 figures. A 1:1,000,000 soil map of Bulgaria compiled by Ye. Tanov is a supplement to the work.

The monograph, which consists of five sections, opens with a brief account of the historical development of soil science in Bulgaria and its present state (compiled by Yenikov, Kolarova, and Tanov).

The first section "The conditions of soil formation" examines the country's climatic features, geomorphological structure and vegetation and the effect of human activity on the soil. Although this section, which has been written by Academicians Gerasimov and Stoyanov, and by I. Stranskiy, is short in comparison to the other sections, it describes the conditions of soil formation comparatively fully and explains clearly why the country has such a considerable diversity of soil types.

It is noted that the climate of Bulgaria is midway between the maritime climate of Western Europe and the continental climate of Eastern Europe. These climatic features are aggravated by orographic complexity—the Frakian lowland has a sub-meriterranean climate. The features of the country's relief are connected with the geological structures, with tectonics and with other changes of the earth's crust. The youthful contemporary relief is emphasized, and the considerable diversity of the vegetation—more than 3,000 species of higher plant in so small a territory—is noted. The main groups of herbaceous vegetation and of trees are examined. Emphasis is laid on the great influence exerted by man on the formation of the present day soil profile by cutting trees, the development of agriculture, irrigation and other measures. Differences in socio-political patterns have meant that man's influence has been unequal under different historical conditions. Agriculture developed in Bulgaria in Neolithic times. Under socialism, man's influence is directed towards an increase in soil fertility.

The second section (Antipov-Karatayev, Gerasimov, Tanov, Palaveyev, Galeva, Dem'yanov, Yenikov, and Vylkanov) is the longest and the most informative. It examines and describes the separate soil groups in conformity with the classification and nomenclature elaborated in 1947 by Gerasimov and Antipov-Karatayev. The typical features of the separate soil groups and the classification principles are indicated and there is a fairly detailed account of the morphological, chemical, mineralogical, physical and agricultural features of the chernozems and grey forest soils of Northern Bulgaria, the chernozem-smol'nitsa and cinnamon-brown forest soils of Southern Bulgaria and of the brown forest, mountain-meadow and mountain-forest dark soils of mountain districts and the saline, alluvial-meadow, meadow-bog and other soils of the country. There is also a full description of the recently-discovered but widespread yellow podzolized soils. Their existence in the Strandzhi district shows that the influence of the humid sub-tropical climate extends to the Bulgarian coast of the Black Sea, a fact which is of interest in relation to the possibility of cultivating certain sub-tropical plants in this region. There is an extremely valuable comparison between the Bulgarian chernozems, brown forest, cinnamon-brown forest, yellow podzolized and other soils and similar soils in the USSR and other countries, from which the specific features of Bulgarian soils can be revealed. The regional features of

Bulgarian chernozems are described and attention is paid to the distinction of carbonates in the form of pseudomycelium and to the considerable thickness of the humus horizon that is responsible for the special water and heat regimes of the Danube plain soils. The special features of cinnamon-brown forest soils are shown to be: the predominance of leached and podzolized subgroups; extensive formation of clay and accumulation of the hydroxides of iron and aluminum; and the laying down of carbonates in the profile; that is, associated with the bioclimatic conditions of soil formation. The disputed question of the origin of the specific smol'nitsa soils of Southern Bulgaria has been largely resolved. Two basic features have been shown to be involved in their formation: firstly, the clay composition of the parent material (mainly products of the weathering of andesites) and secondly the meadow or meadow-bog conditions under which organic matter accumulates when surface drainage is slight. Smol'nitsa soils have been shown to be associated with cinnamon-brown forest soils. Data obtained from studies of the country's saline and solonetz soils are summarized. The classification of these soils in relation to the nature and degree of salinization is made more precise, considerable light is thrown on a number of aspects of their genesis and the hydrological conditions of their formation, and measures for their improvement and the main trends of further research are indicated.

The data here published for the first time concerning the mineralogical composition of the main Bulgarian soil groups, the qualitative and quantitative composition and forms of humus, and the chemical composition of the soil-forming parent materials are of great significance for an explanation of some aspects of soil genesis. The data from X-ray, thermographic and electron microscope analyses of soil colloids are completely new. There are good morphological, chemical and physical data for the soil groups. The agricultural qualities of the soil groups are evaluated and there are valuable instructions on how to increase soil fertility. Data from research stations in various parts of the country on fertilization, cultivation, crop rotation and others are used in assessing and describing soil fertility.

The third section (Antipov-Karatayev, Tyurin, Kolcheva, Voynova-Raykova, Raycheva, Dinchev, Yenikov, Galeva, Dem'yanov, and Vylkanov) contains a comparative description of the genetic soil groups. Certain general statements and conclusions concerning the processes of weathering and soil formation in Bulgaria are arrived at from data on the mineralogical and chemical composition of the main soils. The concepts of the formation and transformation of clay minerals in relation to the type of weathering and soil formation and also to the nature of the soil-forming parent material here advanced will provide a valuable preparation for further study of the genesis of soil groups and subgroups in Bulgaria.

Organic matter and nitrogen in soils are examined in the same section and the total contents of humus are given in metric tons per hectare for the main soil groups. It is noted that the total contents of humus in the Bulgarian chernozems are small by comparison with the corresponding soils in the Soviet Union. Study of the composition of the humus in chernozems and chernozem-smol'nitsa soils reveals that there is some condensation of the humic acids and formation of humins, which is thought to have a positive effect on the resistance of the humus to destruction. There is a relatively high fulvic acid content in the humus of cinnamon-brown soils. Data are given concerning the connection between the acids in humus and the mineral part of the soil. It is pointed out that calcium humates play the principal role in the aggregation of chernozems and chernozem-smol'nitsa soils, while humins and fulvic acids mainly associated with the oxides of iron and aluminum fulfill this role for cinnamon-brown and brown forest soils.

A microbiological description of the soils is included in the same chapter. There is a detailed account of ammonifying, nitrifying and nitrogen-fixing bacteria, actinomycetes, microscopic fungi and cellulose-decomposing microorganisms. The part played by microorganisms in soil formation and in increasing soil fertility is stressed.

The comparative agronomic, meliorative and chemical description of the main soil groups is of considerable practical significance.

Soil erosion and its control are considered in the fourth section (Biolchev, Pimpirev, and Georgiyev). Natural conditions in Bulgaria are favorable to the extensive development of erosional processes. The authors examine the role of forest and grass vegetation (grasses and legumes—sainfoin, lavender, etc.) as control measures. Mention is made of national resources for controlling erosion in the form of plowed terraces, agricultural practices, etc.

In the fifth chapter (Tanov), the country is divided into soil regions by uniformity of the soil. The territory of the People's Republic of Bulgaria is divided into 15 regions, a detailed description of the soil conditions is given in this chapter. The division is of importance to distinguish between the various farming and other practices undertaken by agricultural organizations.

"Soils of Bulgaria" marks an important stage in the development of Bulgarian soil science and the material that it summarizes makes it a valuable reference work for Bulgarian specialists. Although some faults were found, they do not detract from the great value of the book. Some of the subchapters in the third section of the book, for example, are unduly long, the exposition and style of the individual authors has not been adequately reconciled, and the data of authors who did not help to write the book have not been made sufficient use of in the description of individual soil groups (Zonn's data on the forest soils of Bulgaria are a case in point).

The monograph is an example of a many-sided collective work. A considerable number of Bulgarian soil scientists took part in the field work directed by the Soviet scholars Antipov-Karatayev and Gerasimov. The soil scientists of Bulgaria, who are mastering Dokuchayev's methods and ideas, have close associations with Soviet soil science, which plays a leading role on a world scale.

The publication of this work in Russian by the USSR Academy of Sciences has additional importance for us as Bulgarian soil scientists. It will bring a knowledge of the soils of Bulgaria both to the Soviet reader and to soil scientists in many other countries. The book testifies to the great success of the young Bulgarian soil science and is its pride.

In expressing our deep gratitude to the authors of this valuable monograph, and especially to I. N. Antipov-Karatayev, I. P. Gerasimov, and I. V. Tyurin, the leaders of the team, we venture to hope that cooperation between Soviet and Bulgarian soil scientists in the interests of the science and for the good of our peoples, who are building their happy life in peaceful labor, will both continue and be extended in the future.

Reviewed by Ts. Staykov and L. Raykov

THE FORCES OF THE LAND (STORIES ABOUT THE SOIL),

BY V. ALEKSANDROVA

State Publishing House for Children's Literature of the USSR, Ministry of Education, Leningrad 1958, 182 pp.

There is a dearth of popular accounts of the soil for the general reader. With the exception of Professor Kachinskiy's book, which has appeared in many editions and been translated into many languages, it would be difficult to cite a book that is accessible to the nonspecialist reader. The appearance of a popular book on the soil, and one, moreover, that has been written for school children and published in the series "Scholars' aids," is, therefore, a gratifying event. The book is especially welcome in view of the almost total lack of information on the soil in middle-school textbooks and of the lack of agreement, contradictory nature and, on occasion, low accuracy of the information that is given. Let us return, however, to the book under review. Its great merit is the breadth of the background information. The author gives a great deal of information drawn from the history of science, and not only soil science but also, in the main, botany, chemistry and other branches of natural science, and many interesting facts from the history of agriculture. He also gives an account of contemporary achievements and methods in related sciences (the use of tagged atoms, for example). This information helps to clarify many aspects of soil formation. Thus, for example, physiological data on plant nutrition and their construction of organic matter from atmospheric carbon dioxide provide the basis for explanation of the development of soil fertility and the accumulation of nutrients in the soil. Nevertheless, the background information is sometimes too little related to the subject and tends to acquire a separate existence two or three planes removed from the main theme — the soil: some of the background information is unnecessary: one can hardly see the point of telling school children, in a popular book about the soil, that lists of notorious drunkards were kept in ancient Greece and that one such person was known as "the funnel," nor does the author serve his ends by telling us how many victims were tortured by the inquisitor Torquemada, and so on.

The book is attractively and stylishly written, a fact of some importance in a popular work, especially when it is intended for a juvenile readership. There are many literary quotes, which help to explain the author's thoughts to the reader and present his ideas in a more vivid and expressive form. Unfortunately, however, the author has once again somewhat exceeded the bounds imposed by a sense of balance and correct proportion. Some of the quotations, such as a one and one-half page extract from Mayakovskiy's propoganda pamphlet on the need to combat drought by scientific agriculture and not by prayer, are too long, while others, such as the extract from Oscar Wilde's story of the death of Lord Canterville, bear too tenuous a relationship to the subject under discussion.

In the section of the book devoted to the soils of the main natural regions of the Soviet Union, the author goes into considerable detail on the natural features and agriculture of the regions and speaks of ways of increasing soil fertility. This information, coupled with the details on the factors of soil fertility given in other parts of the book, is a valuable feature.

There are some errors of fact and badly expressed ideas. Thus, for example, it is hardly correct that the loess on which chernozems develop should be called loess-like clay loam or that carbon should be mentioned in relation to the composition of basalt and granite. Since the work of Schmidt and Fesenkov it is impossible to advance the Kant-Laplace hypothesis on the origin of the Earth as being both accurate and generally-accepted, nor, when speaking of molecules, should one say that "molecules of nitrogen and oxygen fly in the air" (p. 55).

The drawings have been made with a sense of humor and are in keeping with the style and the requirements of the readership: they are a valuable addition to the text. The same cannot, unfortunately, be said of the color map given with the book, which is entitled "The Soils of Our Country," although it shows vegetation and the soils are given in the explanatory text. The map has been carelessly prepared, the conventional signs are lost among the soil and landscape contours and sometimes fail to agree with the colors on the map (e. g., the symbol for semi-desert). The drawing of mountain contours given beneath the map is very inexpressive.

Despite these faults the book is of positive value. If the author accepts the comments made in this review I trust that he will increase the amount of information directly related to the soil when he comes to prepare the second edition (that will, I hope, be found necessary).

Reviewed by V. M. Fridland

STORIES ABOUT THE SOIL (FOR MIDDLE-SCHOOL STUDENTS),

BY B.N. POL'SKIY

Uchpedgiz, 1958.

There are many fascinating books for the young reader that are devoted to the romantic work of the geologist or builder, aviator or sailor. It is not easy to write an absorbing account of the soil, its formation and the complex processes that take place within it. B. N. Pol'skiy has attempted this task and, it must be said, has been conspicuously successful.

It has already been shown (Pochvovedeniye, 1958, No. 8) that the attention paid to the study of soils in school curricula in geography is quite inadequate (the same applies to the natural sciences). The publication of this book, which is a popular account of the soil, its fertility, soil groups, living organisms in the soil, structure, cultivation and other aspects, is therefore timely.

The book opens with a section "What is soil," in which the author gives an interesting account of the celebrated journey by the founder of Russian soil science, Vasiliy Vasil'yevich Dokuchayev, through the chernozem steppes of Russia. This journey provided the author with extensive material, which he used in his famous work "The Russian Chernozem," published in 1883. This work contained the first truly scientific answer to the question — what is the soil and how is it formed? Pol'skiy introduces the reader to Dokuchayev's definition of soil and gives an account of the formation of humus in the various horizons and of the age of the soil.

An amazing property of the soil — its fertility — is dealt with in the next section. Here the author introduces the extremely simple and clear definition of soil fertility given by Vil'yams and shows how plants extract the nutrients from the soil and the role of humus as a source of plant food. The fertility of the soil is successfully illustrated by the celebrated example of a grain of wheat in Jules Verne's "The Mysterious Island," in which he related the quantity of bread that can be obtained from a single grain in successive harvests. This miracle-working power of a single grain is illustrated by a drawing.

The section "What kinds of soil are there" is illustrated by a map of the soil zones on the other side of which there is a map of annual rainfall zones. The students thus see the clear connection between soil zones and climatic belts. This is the central section of the book, in which Pol'skiy sets out to describe the soils in the country's natural zones. Information is given on the specific features, distribution and formation of the soil in each zone. The reader is introduced successively to peaty-podzolized soils, gray forest soils, chernozems and chestnut soils. There is an account of the correct way to take monolith soil samples that will be useful to the pupils. In his account of the chernozems, the author gives some interesting information on the work of the "second founder of Russian soil science," P. A. Kostychev.

Young readers will find an interesting account of the constant inhabitants of the soil (minute microorganisms, the profusion of different types of insect, worms and small animals that perform such a large amount of useful work) in the section "The soil population." Some of them make the necessary nitrogen available to the plants direct from the air. Others help the plant to assimilate its food. Various bacteria that convert ammonia to nitric acid play a large part in supplying the plant with nitrogen.

In the section "The life of the soil" Pol'skiy gives an account of the active life of the soil, which is revealed in variation in the composition of the soil and in its moisture, heat and total contents of plant nutrients. The soil is able to "breathe." The information given in these sections will undoubtedly give the pupil a new outlook on the soil. The author leads the reader to the conclusion that not all the laws of soil fertility are as yet known to man. Nevertheless, man is able to influence the soil and increase its yield and thus increase the wealth of our country.

The inclusion of a section entitled "Sand and clay" is very welcome. Middle-school pupils are usually concerned with sand and clay. The section examines the concept of soil texture, gives an accurate definition of sandy and clay soils and notes their typical features.

A positive feature of the exposition is that scientific concepts and definitions are explained by examples that are convincing and comprehensible to children. Thus, the role of the small structural aggregate in supplying the plant with moisture and food is explained by a number of very simple examples. The structural aggregate is a "watering can" for the plant and "an excellent jam jar." The part played by grasses and worms in creating soil structure is illustrated.

There are interesting facts in the sections "How the soil used to be cultivated" and "How we cultivate the soil nowadays." The first section describes the primitive implements (digging stick, and primitive wooden plows) used in the medieval Russian state, and the second the highly developed implements for tilling the soil with which modern agriculture is equipped. But the author does not limit himself to a description of the implements. He introduces the reader to the various forms of cultivation and their scientific basis, to plowing, harrowing and hoeing periods and to the various types of fertilization. There is a brief account of Mal'tsev's cultivation methods and a photograph of the plow recommended by this scientific grower of field crops.

I shall not deal with the content of the remaining sections of the book, but their subject matter merits inclusion as it increases the pupil's knowledge.

The book is well illustrated with color photographs and drawings of soil monoliths of various groups. Some of the photographs are, however, blurred and not very revealing.

There is an unfortunate error on p. 92, where it is stated that "up to three and a half cubic liters of water per hectare would have to be poured onto the soil to leach out its salts. This means that a 35 cm layer of water would have to be poured onto the surface." It is quite easy to show by calculation that in this case the layer of water would be only 0.35 mm.

The book will undoubtedly be of great value to the young reader to whom it is addressed and will explain many difficult questions concerning the formation of the soil and the processes that occur within it.

Middle-school teachers of geography and biology can use the book in class.

Reviewed by A. Plashchev

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